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FINAL REPORT

DUAL-MODE MANNED/AUTOMATED LUNAR ROVING VEHICLE DESIGN DEFINITION STUDY

Volume II
Vehicle Design and Systems Integration

Book 4
Systems Safety Analysis

(NASA-CR-119309) DUAL-MODE MANNED/AUTOMATED LUNAR ROVING VEHICLE DESIGN DEFINITION STUDY. VOLUME 2: VEHICLE DESIGN AND SYSTEMS INTEGRATION. BOOK 4: SYSTEMS SAFETY ANALYSIS Final Report (Bendix Corp.) 00/18

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FINAL REPORT

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Volume II
Vehicle Design and Systems Integration

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Systems Safety Analysis

BSR 2816
January 1970

Prepared for:

George C. Marshall Space Flight Center
Under Contract:
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THE BENDIX CORPORATION
Aerospace Systems Division
Ann Arbor, Michigan

LIST OF BOOKS COMPRISING DLRV FINAL REPORT

FOREWORD

This final report presents the results of the Dual-Mode Lunar Roving Vehicle (DLRV) design-definition study performed for the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, under Contract No. NAS 8-24528. The study was performed by the Aerospace Systems Division, Bendix Aerospace-Electronics Company, under the direction of Mr. J. A. Burns, Program Director, and Mr. R. E. Wong, Engineering Manager.

The program was directed by the Lunar Mobility Task Team, Advanced Projects Office, MSFC under Mr. R. D. Stewart, Task Team Manager.

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SECTION 1

INTRODUCTION

This book presents the results of the DLRV System Safety Analysis performed as Task K of the Bendix DLRV Phase B study program.

In general, the system safety studies were performed in three steps: (1) Preliminary Hazard Analysis which consisted of defining and listing all foreseeable hazards, (2) System Safety Analysis, which consisted of investigating system, subsystem, interface, critical components, and procedures techniques for evaluating the criticality of the hazard and the design or procedures techniques for eliminating or minimizing specific hazards, and finally, (3) Operating Safety Analysis, which consisted of a mission profile review of the dominant DLRV operating hazards to summarize recommendations to be considered during system development and operational use.

The System Safety Analysis also includes highlights of safety investigations and analyses performed under other Phase B study tasks, e.g., Task E, Lunar Surface Hazard Detection and Avoidance.

Section 2 reviews safety study requirements and criteria which were applied to the system safety study with emphasis on mobility characteristics, crew safety considerations, and the steps to be followed in the safety study per se.

Section 3 reviews Preliminary Hazards Analysis results, viz., the safety considerations which were applied to evaluation of the selected DLRV configuration, followed by a mission phase and subsystems oriented summary of safety hazards.

Section 4 summarizes safety analysis results in major areas of study including DLRV static and dynamic stability, energy source evaluation, areas of astronaut safety, failure modes and effects analysis, and other areas which influenced design and operational safety.

Section 5 presents a mission sequence summary of DLRV hazards and recommendations for control.

Appendix A illustrates suggested safety requirements and constraints for the preliminary system specification.

Appendix B provides failure modes and effects analytical detail and critical components determination data generated in support of the system safety study.

SECTION 2

PRELIMINARY SAFETY REQUIREMENTS

2.1 GENERAL

The study program Statement of Work defined the System Safety Analysis as Task K of the Phase B DLRV Study and required that a system safety analysis be performed to assure that system safety received specific documented consideration in the areas of: (1) Preliminary Hazards Analysis, (2) Systems Safety Analyses, and (3) Operating Analysis.

Additionally, the Statement of Work required that the DLRV be specifically designed to prevent single-point failures from aborting the vehicle missions (and endangering crew safety).

This requirement established the need for system/subsystem/critical component failure modes and effects analysis to be performed as a supporting element of the design and safety studies.

In conjunction with the System Safety Study Task, a Task E, "Hazard Detection and Avoidance Subsystem Design and Analysis," was implemented during the study program to provide special attention to the remote control mission of detecting and safeguarding the vehicle against traverse hazards during the unmanned traverse.

2.2 STUDY CRITERIA

2.2.1 Mobility Requirements

Part 3 of Annex C to the DLRV Statement of Work provided initial criteria for minimum mobility requirements. The following minimum mobility requirements were taken as basic measures for safe vehicle operation on the lunar surface:

1. Minimum Step Obstacle Capability with both front wheels in contact with obstacle at the same time starting from zero velocity: 1 m in unmanned mode, 30 cm in manned mode

2. Minimum Crevasse Capability: 1 wheel, 70 cm, unmanned; 2 wheels, 1 m, unmanned; 2 wheels, 70 cm, manned

3. Minimum Static Stability: 45 ° in lateral or pitch attitude, 45° in longitudinal or roll attitude.

2.2.2 Crew Safety Considerations

Astronaut capabilities, limitations, and hazards criteria for the DLRV study were provided with the study Work Statement and in other source material provided by NASA. These data were initially compiled for program use in Bendix Document LTM-32 and later updated in Bendix Document LTM-34, "Preliminary Crew Systems and Operations Requirements and Criteria for Lunar Roving Vehicles," 5 July 1969.

The most significant criteria from the safety standpoint included the following:

1. Protection of the astronaut from thermal, mechanical, radiological, electromagnetic, pyrotechnic, visual, and other hazards

2. Adequate space and volumes for the astronaut to allow for his free movements in performing both normal and emergency conditions

3. Adequate physical, visual, and auditory links between the astronauts and their equipment under both normal and emergency conditions

4. Provisions for the safe astronaut task performances under reduced gravity with safeguards against injury, equipment damage, and disorientation

5. Adequate natural or artificial illumination for operations and controls

6. Safe provisions for ingress, egress, and driving under normal, adverse, and contingency modes

7. Provisions to minimize stress and fatigue

8. Adequate systems for contingency management, survival, and rescue

9. Design to prevent accidental or inadvertent operation of critical functions and to minimize potential human error in the operation of the system

10. Protection to prevent DLRV overturn

11. Checkout provisions for each traverse

12. Redlines for hazard indicators

13. Contingency procedures for emergencies

14. Shock and vibration levels acceptable to crew

15. Emergency provisions for vehicle entrapment

16. Performance definitions for degraded modes

17. Warning instrumentation for vehicle stability

18. Parking brake provisions for emergency

19. Warnings for vehicle power reserve

20. Warnings for critical mobility malfunctions

21. Vehicle stability control during deployment

22. Not live electrical connections for crew operations during EVA

23. Protection of the EMU from debris and dust.

2.2.3 System Safety Investigation and Analysis

The scope and depth of the Phase B safety studies were defined by internal Bendix Document 962-S1 to provide for a three-step documentation of the safety study: (1) Preliminary Hazards Analysis, i.e., the identification of all foreseeable hazards, (2) System Safety Analyses, e.g., the investigation of critical hazards for elimination, reduction, or for further action during development, (3) Operating Safety Analyses, i.e., the timeline summary of critical DLRV hazards with recommendations for further action during development.

The Preliminary Hazards Analysis (identification) study results are described in Section 3.

The System Safety Analysis of critical system and interface hazards is described in Section 4.

The Operating Safety Analysis timeline summary and development recommendations are described in Section 5.

SECTION 3

PRELIMINARY HAZARDS ANALYSIS

3.1 CONFIGURATION SELECTION

3.1.1 General

Up to the time of the Phase B DLRV configuration selection (presented at the 2nd Monthly Program Review of 10 June 1969, Bendix Report BSR 2723), the system level study program emphasis was placed on: (1) the design of the various vehicle configurations which could be stowed in the LM space available, and (2) the comparative evaluation of the stowage/deployment, mobility, and configuration form factors of the other subsystems common to all vehicle configurations. Eight basic vehicle system configurations were practical stowage/mobility configuration candidates for final review and selection.

3.1.2 Selection Criteria

From a quantitative standpoint, the Mobility Performance Comparison identified and presented the vehicle candidate characteristics of: (1) pitch and roll stability, (2) step obstacle climbing capability, (3) crevasse crossing capability, (4) soft soil slope climbing capability, and (5) ground (boulder) clearance (chassis).

Additionally, the eight vehicle configuration candidates were considered for the following astronaut safety considerations: (1) unloading, deployment, and manned-to-remote conversion tasks including time, complexity, and hazards, (2) RTG thermal radiation exposure, (3)science activity (cargo accessibility), (4) driving ease (normal and reverse), (5) driver location for vehicle stability (cg), (6) passenger contingency (mass and location), and (7) dynamic stability (suspension influences).

For the configuration selection, the sizes, weight, and design definition of the vehicle power, crew station, communication, navigation, and remote control equipment were based on tentative concepts incorporating redundancy, safety features, and backup modes common to each of the vehicle configurations. Therefore, these factors were not sensitive considerations in the configuration selection.

3.1.3 Selection

Four of the eight vehicle configurations defined by the study were double-folded suspensions for stowage on the LM. The initial reason for double folding was to obtain larger wheel spans for roll stability. However, several of the single-fold configurations were found to meet or exceed the minimum 45° pitch and roll stability requirements with less complexity and lower weight. Complexity of horizontal stowage and unloading ruled out all except a baseline six-wheel single fold (6/6-SF) concept and a four-wheel manned/six-wheel unmanned (4/6-SF) configuration.

Minor safety advantages for the 4/6-SF were: (1) elimination of the RTG from the manned mode mission, and (2) lower vehicle complexity of the four-wheel concept during manned mode operations.

The 6/6 configuration was chosen, however, for lower weight and also because it had obstacle climbing advantages and would be more readily available for remote control mode operation in the event of a hasty departure of the astronauts from the lunar surface.

3.2 HAZARDS IDENTIFICATION

3.2.1 General

By means of internal Bendix document 962-S2, Preliminary Hazards Analysis, all general specific hazards which were identified during the study program were incorporated into a checklist for use by design, safety engineering, and other groups as a study aid to eliminate or minimize these hazards during the Phase B effort.

The following subsections itemize the hazards listing by mission phase and subsystem functional categories. Sections 4 and 5 present subsequent analysis and summary data for the more critical crew and mission hazards.

3.2.2 Potential Factory Assembly and Test Hazards

1. Degradation of thermal coatings, optical thermal control surfaces, or fragile insulation during DLRV assembly and checkout handling

2. Damage to DLRV chassis, crew station, suspension, and wheel structures designed for 1/6-g loads during DLRV assembly and checkout handling

3. Battery fire and explosion hazards during DLRV development testing

4. Thermal hazards to test personnel during RTG simulation tests with RTG fuel simulators

5. Toxic hazards from beryllium machining particles in the processing of beryllium forgings for traction drive mechanisms (TDMs)

6. Possible flammability hazards of change-of-state materials during the fabrication of radiator heat sinks

7. Possible radiation hazards from IR Hazard Detection Sensors or Directional S-Band Antenna during factory functional test.

3.2.3 Potential Shipping, Handling, and Storage Hazards

1. Degradation of thermal coatings, optical thermal control surfaces, or fragile insulation during DLRV preparation for shipment, shipping, and storage modes

2. Damage to DLRV chassis, crew station, suspension, and wheel structures during LRV preparation for shipment, shipping, and storage modes.

3.2.4 Potential Prelaunch Preparations Hazards

1. Possible damage to TDM and SDM dynamic seals during KSC functional checkout of traction and steering performance

2. Possible physical damage to DLRV thermal coatings, thermal control surfaces, and fragile insulation during KSC checkout handling

3. Possible damage to DLRV connectors if make/break connections are made at KSC, or from excessive connector cycling

4. Possible crew station damage if astronauts or other test operators operate Crew Station at KSC

5. Possible science tiedown device damage during KSC fit check operations

6. Battery fire and explosion hazards during battery cell formation, charging, and discharge calibration operations at KSC battery shop

7. Possible ordnance detonation hazards from EMI/RFI or inadvertent electrical actuation of explosive decouplers which may be used for DLRV vehicle or science deployment equipment

8. Possible radiation hazards from IR Hazard Detection Sensors or the Directional S-Band Antenna during KSC functional tests

9. Integration tests causing detonation hazards of active seismic experiment equipment if used on DLRV during integration functional tests at KSC.

3.2.5 Potential Installation and Checkout on LM Hazards

1. Damage to LM quadrant mechanical interfaces or LM thermal control blankets during LM fit check and installation sequences

2. Damage to DLRV Tiedown and Unloading Subsystem during LM fit check and installation sequences

3. Damage to DLRV thermal control or structure elements during LM fit check and installation sequences

4. Possible degradation of TDM or SDM dynamic seals during LM fit check and installation sequences.

3.2.6 Potential Prelaunch Checkout and Standby Hazards

1. Possible wet stand overheating of DLRV flight battery after launch pad installation

2. Possible injury to launch pad crew during DLRV battery installation sequence

3. Possible injury to launch pad crew during DLRV or RGM RTG installation sequences

4. Possible loss of RTG cooling provisions on launch pad after RTG installation

5. Possible injury to launch pad crew during RTG or battery removal back-out procedures.

3.2.7 Potential Launch, Spaceflight, and Lunar Landing Hazards

1. Possible loss of DLRV tiedown integrity during launch, spacecraft maneuver, and lunar landing forces

2. Possible loosening of DLRV folded or chassis-borne equipment during launch, spacecraft maneuver, and lunar landing forces

3. Possible loss of DLRV thermal control provisions for RTG, battery, or other critical components during launch to landing modes

4. Possible damage to DLRV from LM RCS plume during lunar landing sequences.

3.2.8 Potential Unloading and Deployment Hazards

1. Possible injury to astronaut by DLRV unloading apparatus during DLRV unloading sequence, i.e., equipment falling on astronaut

2. Possible damage to LM thermal insulation during the DLRV tiedown release and deployment sequence

3. Possible astronaut activity hazards in the sequence of joining the fore and aft sections of the DLRV

4. Possible astronaut activity hazards associated with handup and work-around procedures in the event of malfunctioning tiedown release or deployment devices

5. Possible backlash from crank winches during deployment

6. Stability of the astronaut performing winch operations on the LM ladder

7. Structural integrity of the LM ladder for astronaut deployment activity

8. Adequacy of lighting and crew visibility for any sun angle and/or shadow conditions for deployment operations

9. Possible hazards of unfavorable lunar surface below the DLRV stowage quadrants, ice, slopes, obstacles, dust, etc.

10. Possible astronaut errors during the DLRV deployment sequence.

3.2.9 Potential Lunar Surface Feature Hazards

1. Ability of DLRV operator to discriminate hazardous obstacles, crevasses, slopes, and other lunar surface irregularities at 16 km/hr and lower vehicle speeds

2. Possible need to employ remote mission hazard detection sensors as a backup to manned mode operations

3. Possible hazards of driving through surface shadowed areas

4. Possible hazards of operating DLRV in extended shadow areas, e.g., under a cliff

5. Possible hazards of driving directly into or away from the sun

6. Hazards detection limitations of TV for obstacle, crevasse, slope, and soft soil hazard detection

7. Hazards associated with the use of nonimage RF sensors: (a) when operating with TV in continuous mode, (b) when operating without TV in the step mode

8. Hazards associated with the use of Facsimile camera when employed as a backup to TV

9. Single point or mission critical components employed in DLRV hazard detection subsystem

10. Possible loss of status sensors on safety of hazard detection or emergency stop control functions.

3.2.10 Potential Mobility Operational Hazards

1. Astronaut walkback from an immobilized or disabled vehicle (analysis of astronaut walkback return not within the scope of the DLRV Phase B study)

2. Possible overturn from exceeding static stability and dynamic stability capabilities of the DLRV

3. Possible chassis hangup on rocks or crater rims
4. Possible DLRV entrapment by crevasses
5. Possible DLRV entrapment in soft soil
6. Possible DLRV loss of traction or vehicle control on loose soil slopes
7. Possible suspension wheel damage, suspension or vehicle damage by contact with unyielding obstacles
8. Possible loss of dynamic stability sensors, computer, or other critical components on manned mode operating safety
9. Possible errors by astronaut in interpreting dynamic stability warnings
10. Possible effect of sudden vehicle acceleration or deceleration on vehicle operator, operating control, or astronaut restraints
11. Possible effect of excessive steering maneuver command on stability of vehicle for various conditions of surface roughness and on slopes
12. Possible effect of excessive braking command on soft soil or other effectively slippery conditions
13. Possible hazards of negotiating maximum specified slopes, obstacles, crevasses, and loose soils, including likely combinations, i. e., fresh craters and operation on irregular slopes
14. Possible total loss of braking, steering, or traction control
15. Possible total loss of DLRV power
16. Possible failure of chassis structure
17. Possible failure of chassis frame members
18. Possible failure of cargo tiedown mechanisms
19. Possible failure of suspension arm bearing assemblies

20. Possible failure of suspension damper
21. Possible failure of suspension arm
22. Possible failure of damper snubbers or limit stops
23. Possible failure of wheel kingpins
24. Possible failure of kingpin bearings
25. Possible failure of SDM spline or SDM spline decouple mechanism
26. Possible failure of wheel bearings in drive mode and free-wheeling mode
27. Possible failure of wheel rims, ring elements, or wheel rigid structure
28. Possible failure of aft unit hitch and/or electrical connections
29. Possible failure of high- and low-speed TDM motors
30. Possible failure of TDM transmission or TDM decouple device
31. Possible failure of SDM motor or SDM transmission
32. Possible failure of Park/Emergency brake mechanism
33. Possible failure of Park/Emergency brake switch
34. Possible failure of high-low transmission switch
35. Possible failure of FWD/REV switch
36. Possible failure of TDM control electronics or power conditioning
37. Possible failure of SDM control electronics or power conditioning
38. Possible failure of hand control stick, servo circuits, or power conditioning

39. Possible failure of hand control grip safety switch

40. Possible failure of TDM or SDM status sensors and warnings

41. Possible failure of TDM or SDM decoupling, power switching, and circuit breaker controls

42. Possible failure of TDM and SDM command decoder.

3.2.11 Potential Navigation Operational Hazards

1. Possible loss of DLRV Navigation Subsystem accuracy

2. Possible loss of RF data links on navigation

3. Possible loss of all power to on-board DLRV navigation

4. Possible loss of DLRV navigation computer

5. Possible loss of direction gyro

6. Possible loss of vertical gyro

7. Possible loss of navigation power conditioner

8. Possible loss of navigation decoder

9. Possible loss of gyro malfunction light

10. Possible loss of navigation data indicator or selector switch

11. Possible loss of bearing indicator or selector switch

12. Possible loss of warning lamp test switch

13. Adverse effect of lunar dust on the operation of navigation equipment.

3.2.12 Potential Communications Hazards

1. Loss of S-band (direct to earth) links

2. Loss of VHF communication functions

3. Loss of electrical power to DLRV communications
4. Effect of lunar dust on degradation of DLRV antennas
5. Loss of omni antenna
6. Loss of S-band receivers
7. Loss of communication command decoders
8. Loss of directional antenna
9. Loss of directional antenna drive mechanisms
10. Loss of microwave network (S-band)
11. Loss of triplexer (VHF)
12. Loss of FM power amplifiers
13. Loss of PM power amplifiers
14. Loss of PM or FM exciters
15. Loss of VHF antenna or diplexer
16. Loss of VHF receivers or transmitters
17. Loss of analog or formatter multiplexers
18. Loss of A/D converter
19. Loss of modulation processor
20. Effect of DLRV communications RFI/EMI on LM or astronaut equipment communications
21. Safe LM radio line-of-sight (LOS) operating area for DLRV manned operations in the event of loss of S-band direct link with MCC.

3.2.13 Potential Crew Station Hazards

1. Debris and dust caused by wheels during turning maneuvers

2. Abrasion of the EMU from seat material, supporting structure, restraints, and lunar dust

3. Potential EMU damage to DLRV second passenger in a contingency mode of operation, i.e., not located in driver seat

4. Degree of control and display interference with astronaut visibility of wheels and/or lunar surface ahead of the vehicle

5. Possible accidental operation of DLRV hand control or C&D switches when DLRV is in motion

6. Possible adverse effect of astronaut seat height in vehicle stability

7. Adequacy of astronaut seating height for recognizing boulders or crevasses in time for turn or stop avoidance actions at 15 km/hr

8. Ability of astronaut to safely step up or down from DLRV without boarding stops

9. Elimination of all sharp edges having a radius less than 0.030 in.

10. Adequacy of seat restraints to protect astronaut from all sudden acceleration, deceleration, and abrupt vehicle motions during traverse on rough lunar surface

11. The need for rear view mirrors or other means to assure astronaut visibility for reverse driving operations

12. The need for hand holds, rails, or other aids to facilitate rapid but safe ingress and egress to the DLRV and to eliminate risks of blind body rotations or backward movements in boarding or debarking

13. Control and display instrumentation adequacy to provide real-time on-board warnings for DLRV dynamic stability hazards, loss of traction, loss of power, loss of navigation direction/range data, or other real-time critical DLRV malfunction conditions

14. Adequacy of manual circuit breaker reset functions for all remedial transient electrical overloads during manned sortie operations

15. Adequacy of astronaut controls to select contingency communication services in the event of critical communication equipment malfunctions

16. Adequacy of remote control telemetry and communications to assist astronaut in detecting and diagnosing DLRV mission or safety critical subsystem malfunction conditions

17. Ordnance or explosive hazards which may result in possible injury to the astronaut or his EMU.

3.2.14 Potential Lunar Night Operating/Standby Hazards

1. Low temperature effects on lubricants and nonmetallic materials which must function during lunar night traverse operations

2. Adequacy of earthshine and TV image sensor for lunar surface feature hazard detection

3. Ability of nonmetallic cable insulations to flex without fracture or crazing during lunar night low temperature conditions

4. Capability of RTG power sources to provide DLRV equipment heater power for minimum operating temperatures and additional power for mobility, astrionics, and science equipment during lunar night survival and/or traverse.

3.2.15 Potential Power Subsystem Hazards

1. Battery fire or explosion risks during: (a) DLRV vehicle operation and standby modes; (b) recharge modes

2. Exceeding safe battery depth-of-discharge limits during manned sortie mode operations

3. Exceeding battery high temperature limits (100°F) during sortie mode operations

4. Exceeding battery low temperature limits (40°F) during lunar surface night standby periods

5. RTG ionizing radiation dosage effects on the astronaut during all planned manned mission activities

6. RTG thermal radiation and contact hazards for the astronaut during all planned man mission activities

7. Possible lunar dust, live connection, or operating difficulty hazards in connecting aft to forward unit cable during deployment

8. Adequacy of shielding, grounding, and filtering of Power Subsystem equipment and distribution to eliminate or minimize the effects of EMI on vehicle astrionics, science, or astronaut communications equipment

9. Possible loss of RTG power during manned and unmanned operations

10. Possible loss of primary vehicle batteries during manned and unmanned mode operations

11. Possible loss of primary power buses during manned and unmanned mode operations

12. Possible loss of series and shunt regulators during manned and unmanned mode operations

13. Possible loss of battery charge regulators during manned and unmanned mode operations

14. Possible loss of deployment battery during manned mode mission

15. Possible loss of power warnings on C&D console during manned mode mission

16. Possible loss of power switch or circuit breaker reset switches during manned mode mission

17. Possible loss of battery ampere-hour sensors during manned or unmanned mode mission

18. Possible loss of Power Subsystem status sensors or telemetry during manned and unmanned mode mission

19. Possible loss of Power Subsystem command decoder functions during manned and unmanned mode mission

20. Effect of extended mission time and charge discharge cycling on DLRV batteries during unmanned mission.

3.2.16 Potential Manual Conversion Hazards

1. RTG ionizing, thermal radiation, and thermal contact hazards associated with installation of RGM science

2. Adequacy of manual installation and alignment of IR radar hazard radar sensors

3. Possible hangup of crew station equipment during folding or removal for conversion

4. Removal of DLRV from LM ascent stage rocket blast and dust dispersion area.

3.2.17 Potential Remote Control Operation Hazards

1. Ability of TV and radar hazard detection to operate vehicle safely in the continuous mode in the event of moon-to-earth communication delays ranging from 6 to 22 sec

2. Ability of hazard radar to detect lunar surface obstacles for turn avoidance or emergency stops in the event that TV may operate only in the step mode, i.e., pictures only when the vehicle is stopped

3. Ability of TV or radar to detect subsurface voids

4. Ability of science facsimile camera to replace DLRV TV for step mode traverse operations

5. Ability of TV to replace medium range hazard radar for obstacle/crevasse detection

6. Ability of Omni S-Band to replace Directional S-band for TV or facsimile camera functions in the event of directional antenna, antenna drive, or equivalent functional loss

7. Ability of TV to prevent pointing of vidicon directly at sun or into a reflecting surface which would cause vidicon damage

8. Ability of DLRV to operate in remote control mode in the event of DLRV navigation equipment item malfunctions

9. Effect of DLRV Power Subsystem equipment item malfunctions on remote control operations

10. Effect of telemetry on Command Decoder equipment item malfunctions on remote control operations

11. Effect of Mobility Subsystem equipment item malfunctions on remote control operations

12. Effect of MCC remote control equipment malfunctions or remote operator errors on safety of manned mission or unmanned mission operations

13. Limited life capabilities of critical components for one-year or longer mission, i.e., batteries, lubricants, hermetic and dynamic seals, suspension dampers, flexible wheels, navigation gyros, thermal control surfaces, and TV vidicon.

3.2.18 Potential Science Interface Hazards

1. 25-kv X-ray radiation hazards of Diffractometer/Spectrometer to ground test personnel during checkout or other science equipment during remote mission

2. Magnetic cleanliness of DLRV for magnetometer experiment operation during DLRV fixed and mobile operating conditions

3. Elevated location of Staff Tracker above astronaut for possible use during manned mode traverses

4. Elevated location of magnetometer experiment booms above astronaut for possible use during manned mode traverses

5. Possible use of ordnance if active seismic experiment is to be employed on DLRV

6. Automated deployment device hangup of RGM or soil sampler equipment resulting in interference with vehicle mobility

7. Vehicle-mounted science interference with TV field of view (FOV)

8. RGM RTG ionizing and thermal radiation hazards to astronaut during installation for unmanned mode conversion.

3.2.19 Potential Natural Environment Hazards

1. Lunar gravity effects on dynamic stability of DLRV during 15-km/hr manned mode operations

2. Lighting glare on reflecting DLRV surfaces (thermal control), displays, and for effect on driving directly toward the sun

3. Lunar shadows distortion of hazardous lunar surface crevasse or obstacle conditions

4. Lunar dust effects on DLRV thermal control, astronaut EMU, and vehicle-borne science

5. Lunar soft soil hazards limiting slope climbing capabilities, or complicating obstacle negotiation

6. Lunar surface crevasse hazards for vehicle entrapment under conditions exceeding wheel width or wheel diameter

7. Lunar surface temperature extremes, lunar day and lunar night effects on DLRV equipment degradation

8. Lunar surface vacuum hazards to sealed equipment and for cold weld phenomena affecting exposed moving metallic surfaces

9. Solar flare radiation

10. Meteroids and micrometeoroids

11. Solar and cosmic ionizing radiation

12. Lunar subsurface voids

13. Unique combinations of lunar surface feature hazards, i.e., fresh craters.

SECTION 4

SYSTEMS SAFETY ANALYSES

4.1 GENERAL

During the course of the Phase B study program, several studies were performed by engineering, safety, and reliability groups in the direct interest of astronaut and equipment safety for the manned and unmanned mode missions.

Vehicle mobility design was based on computer studies of mobility configuration performance for all specified operating conditions on the lunar surface. Total vehicle mass, weight distribution, vehicle geometry suspension characteristics, and TDM/SDM operating characteristics were factored into computer studies of DLRV manned and unmanned configurations to establish the capabilities and limitations of both the Mobility and the Power subsystems. From mobility computer analysis, the DLRV has been determined to be capable of negotiating all specified obstacle crevasse, slope, and soil conditions except for manned and unmanned mode negotiation of the maximum 35° slopes with the minimum specified soil coefficients. The over-all fully loaded vehicle in both the manned and unmanned configurations exceeds the 45° static pitch and roll requirements with dynamic stability greater than 40° at manned mode speeds and traverse conditions.

The DLRV Power Subsystem has been sized by computer studies in concert with mobility computer studies to size adequately the RTG and battery power sources for normal and contingency mode operations. Manned mode emergency return reserves of at least 10-km capability have been provided in each battery in the event that either should fail near the end of the manned mission. The remote mission power has been sized to allow 20% margin for traverse and detours on smooth mare, rough mare, hummocky uplands, rough uplands, and fresh crater profiles of the 1000-km mission.

The DLRV unloading and deployment was designed with crew engineering factored into the minimizing of astronaut activity and avoidance of crew hazards in the unloading, deployment, and checkout sequence.

The DLRV driver station, displays, controls, and crew accomodations were designed with crew engineering factored into achieving equipment and operating procedures which are well within astronaut capabilities and limitations, and characterized by the avoidance of mechanical, electrical, thermal, and operator error hazards.

Mobility, Power, Communications, Hazard Detection and Avoidance, and Remote Control equipment subsystems and components were designed with failure modes and effects considerations to achieve maximum redundancy and alternate mode backup flexibility allowable within the total system weight constraint.

Natural environment hazards and science interface hazards were given particular attention by design, safety, and system engineering to establish design and operating procedure techniques for avoiding or minimizing the effects of hazards unique to the DLRV mission.

Investigation, design data, procedures, and other information pertinent to the more important or critical hazards considered during this Phase B study are presented in the subsections which follow.

A mission sequence summary of the most critical hazards for DLRV is discussed in Section 5.

4.2 DLRV STATIC AND DYNAMIC STABILITY

As illustrated in Figure 4.2-1, the stability of the vehicle can be characterized by its static overturn limits, side slope chassis lean in roll, and its limits when obstacles are encountered by the uphill wheels.

The upper horizontal lines on manned and unmanned mode illustrations of Figure 4.2-1 represent theoretical stability limits for the vehicle on a smooth slope.

On other slopes the lean of the chassis due to suspension deflection plus the additional roll angle caused by the vehicle passing over an obstacle on the uphill side results in lowering of the stability angle as shown for various obstacle sizes and speeds. These effects were taken into account in the mobility dynamics computer simulation program which produced the data presented.

As shown by the stability envelope illustrations, the dynamic stability of the DLRV approaches the inherent static stability characteristics of the vehicle within a range of less than 5° over the regime of allowable speed and terrain roughness. Moreover, since the vehicle is limited to operation on slopes of up to

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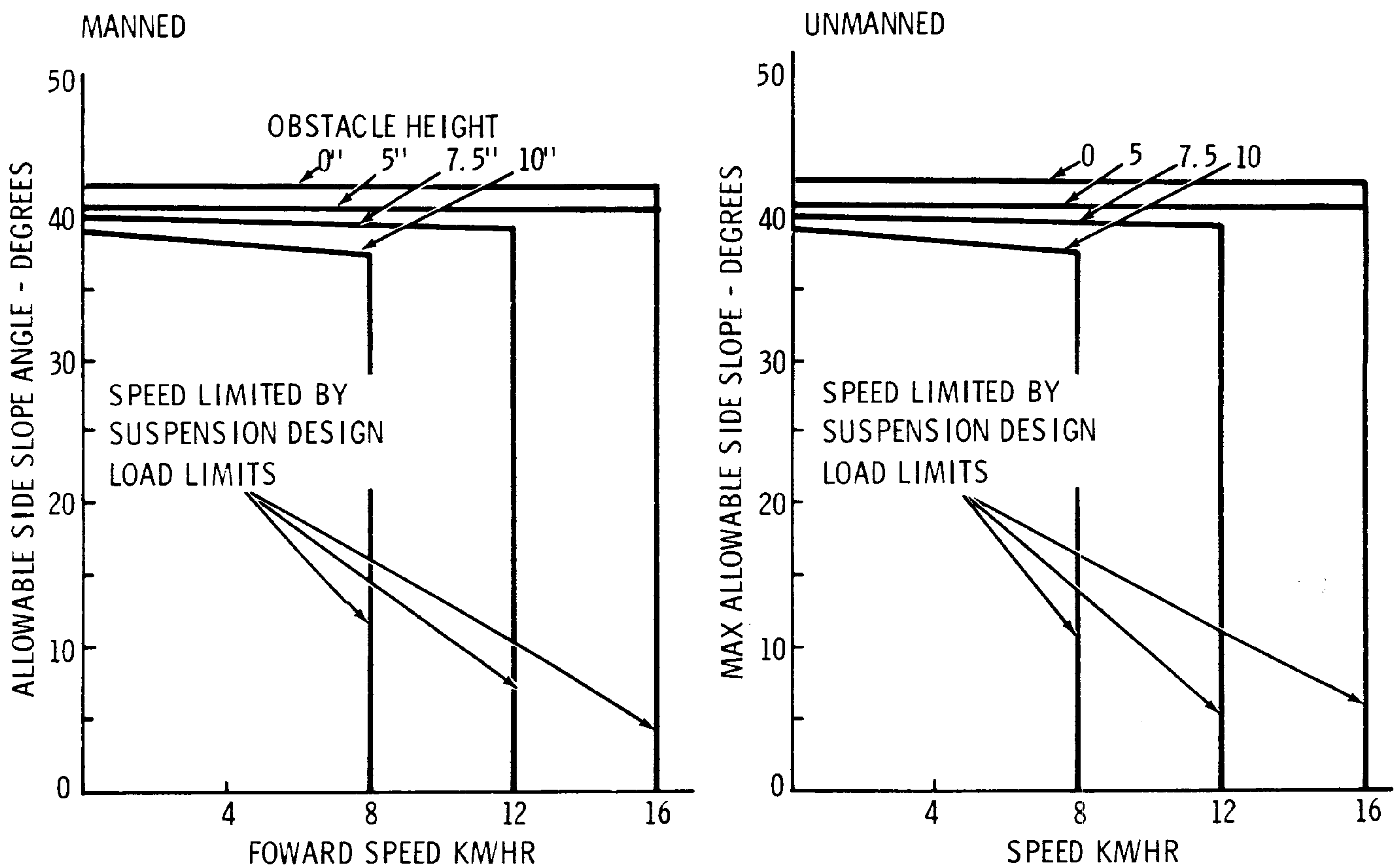


Figure 4.2-1 Static and Dynamic Stability

35° by mobility requirement definition, and may be as low as 30° as a result of local low soil coefficient, it is unlikely that the inherent static or dynamic stability characteristics of the vehicle will be approached by straightforward driving operations on the lunar surface. Thus, for manned mode safety there is a margin on the order of 10° between the maximum slope operating conditions and the inherent dynamic stability of the vehicle. Driving the DLRV with an unbalanced load (shifting of science, etc.) within reason will not degrade the data presented.

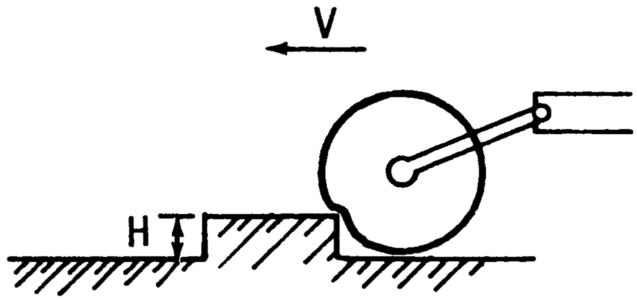
With regard to DLRV dynamic stability under maximum turn rates, the fully loaded vehicle in the manned mode may experience a chassis lean of about 4° on hard soil surface at 16 km/hr. The effect on roll stability is no greater that experienced in traversing small obstacles within the allowable suspension absorption capabilities. The combination of small obstacles and maximum turn rates will still provide stability margins between 5° and 10° as compared with inherent vehicle dynamic stability.

Full-speed turns on soft soil will result is less than 4° chassis roll angle lean due to a tendency of the vehicle to skid or slide at speeds lower than 16 km/hr.

Dynamic stability warnings are proposed for the DLRV design to provide additional assurance to the astronaut that his dynamic stability margin is adequate and maintained during traverse operations. However, it is conceivable that these warnings may not normally activate unless the vehicle is driven into a crater or entered into other downslopes which exceed 35°.

4.3 DLRV SPEED AND STRUCTURE DYNAMIC LIMITS

The DLRV forward speed in the manned mode as shown in Figure 4.3-1 will be limited by obstacle heights over 5 in. due to the effects of the combined wheel, hub mass, and suspension spring dynamics. The wheel design results in a non-linear spring rate with a gradually increasing stiffness up to the point where the bottoming snubber is encountered. This occurs at a wheel rim deflection of about 3.5 in. For wheel deflections beyond 3.5 in., the snubber stiffness is added to the wheel stiffness, resulting in an additional stiffness of about 500 lb/in. Likewise, the suspensions can deflect 8 in. (including the 4-in. static deflection) after which a three-times-stiffer bottoming snubber spring is added to the suspension spring to stop the motion of the wheel mass in 2-in. more and at the design limit load of 4 lunar g's. Figure 4.3-1 shows the maximum allowable obstacle height vs. forward speed where the static obstacle requirement of 1 m is shown as the lower end of the curve. However, if the vehicle is in motion prior to encountering the obstacle, the obstacle height will be limited to a value somewhat below the wheel radius and in the neighborhood of 12 in.



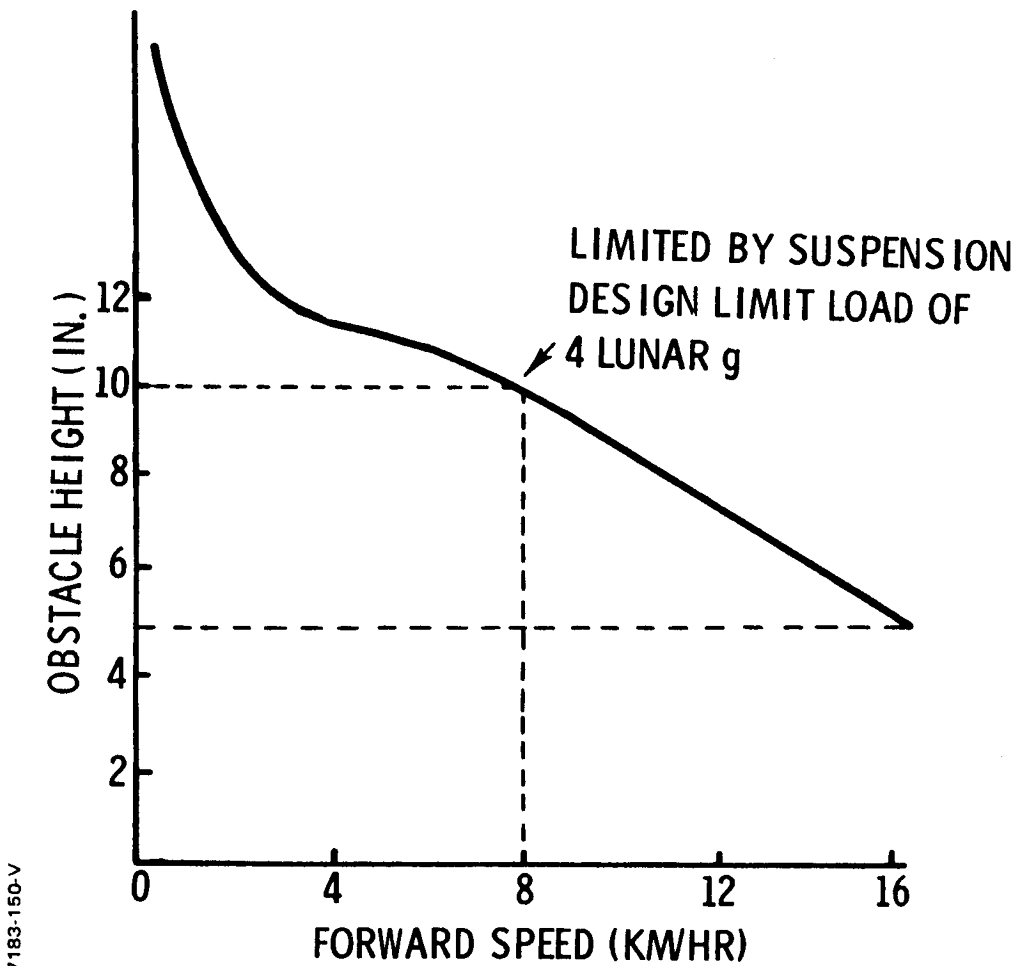


Figure 4.3-1 DLRV Speed and Structure Dynamic Limits

The slope climbing ability for a six-wheel vehicle using two different size wheels is shown in Figure 4.3-2 as a function of ground pressure developed at the wheel. The soil properties assumed are: $\phi = 35°$, density = 100 lb/ft^3, cohesion = 0.05 psi, wheel diameter = 32 in., and wheel flexibility = 40 lb/in. As can be seen, a 35° slope can be climbed with a 10-in.-wide wheel, whereas a 5-in.-wide wheel is only capable of negotiating a slope of 30°.

4.4 SAFE DRIVING VISIBILITY, MANNED MODE

Although no published quantitative analyses exist for visual perception of a space-suited astronaut on the lunar surface, an estimate based on data from the Bioastronautics Data Book, NASA SP3006, indicates an ability to resolve an object subtending an angle of 0.2 minute at 100 ft. Assuming an eye level of 65 in. above the lunar surface, a 30-cm obstacle and a 70-cm crevasse subtend angles of 36 and 4.5 minutes, respectively, at 1000 ft suggesting that no difficulty should be experienced in detecting hazardous surface features beyond the maneuvering capability of the vehicle.

Another consideration for seated height is an 18-in. height requirement to the underside of the knee above the heel line for the seated crewman. This 18-in. height is needed for placing his heels under the PLSS to initiate egress from the vehicle. The crewman must be able to bend forward far enough and bring his heels under him to place the PLSS directly over his feet in order to get up from the sitting position. This is a mandatory requirement for rapid egress. It should be noted that the Bendix DLRV provides rapid egress from the vehicle in one continuous motion and not in a series of step motions. This would be required, for example, if the crewman had to swivel a seat and raise a hand grip into position for egress.

Other additional considerations for the sitting height include providing storage space under the seats for samples under the seat without requiring egress or ingress. Also, keeping the crewman as high as possible maximizes LOS range for radio communications and visual detection with the LM.

4.5 DLRV ENERGY SOURCES AND CONVERSION

4.5.1 Introduction

A review of the DLRV from the energy source (Table 4.5-1) and conversion standpoint reveals an inherently safe vehicle with several minor areas of concern and several requirements for more intensive analysis. The high level of safety relative to other manned space vehicles is due primarily to the use of batteries as a primary power source and the complete avoidance of chemical fuels or

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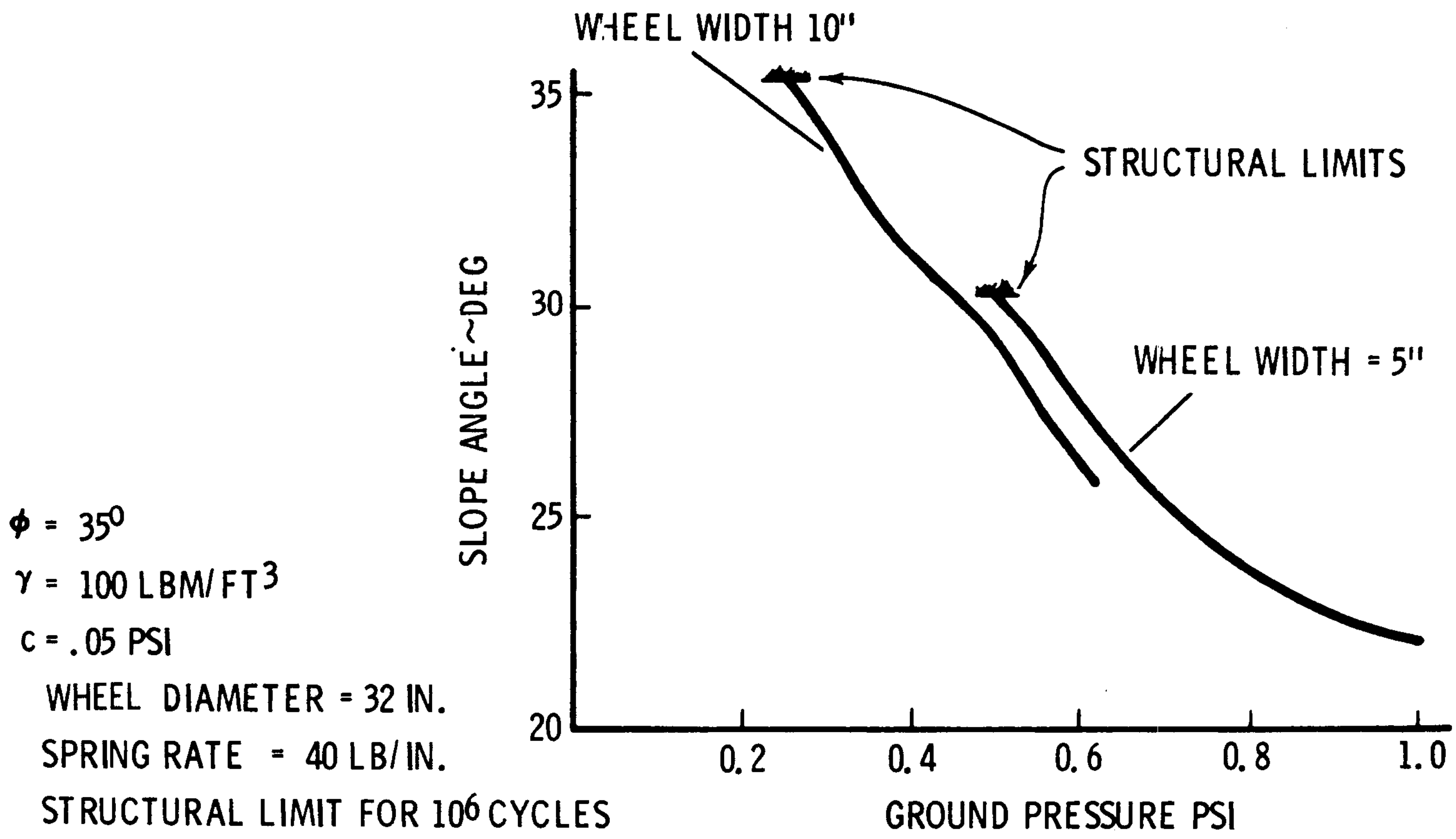

Figure 4.3-2 DLRV Slope Climbing Capability in Soft Soil

TABLE 4.5-1

ENERGY SOURCES

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SOURCE	NUMBER	APPLICATION	VALUE	HAZARD POTENTIAL
BATTERY 60VDC, Ag-Zn	2	MAIN POWER	1.04 KW/HR	PRIMARILY GROUND CHARGING & HANDLING
	1	DEPLOYMENT POWER	80 W/HR	
PRESSURE VESSELS	6	TDM REMOTE DE-COUPLING DEVICES	NOT YET ESTABLISHED	UNDETERMINED
PRELOADED SPRINGS	6	SUSPENSION ARM EXTENSION	NOT YET ESTABLISHED	INADVERTENT EXTENSION DURING GROUND HANDLING
RADIO FREQUENCY RADIATION	1	S-BAND ANTENNA	= 4.5 MW/CM^2	NON, TLV = 10 MW/CM^2
INFRARED RADIATION	1	HAZARD DETECTION SCANNER	AVERAGE 59 X 10^{-5} W/CM^2	AVERAGE EXCEEDS TLV OF 1 X 10^5 CM^2
			PEAK 10^{-9} JOULES/PULSE/CM^2	FACTORY & PRELAUNCH CHECKOUT HAZARD
IONIZING RADIATION	1	RTG	2100 W	-NON-EMERGENCY RADIATION HAZARD ON LAUNCH TOWER SUBSEQUENT TO INSTALLATION OF FUEL CAPSULES
	2	RGM	600 W	CREW EXPOSURE NON-CRITICAL BUT EFFORT SHOULD BE MADE TO MINIMIZE TOTAL MISSION DOSE
			(4) X 3.6 X 10^7 NEUTRONS/SECOND) (E $\leq$ 0.5 MEV)	RADIATOR SURFACE TEMPERATURE OF UP TO 600^0 ARE AN EMU INTEGRITY HAZARD
	1	D-S X-RAY	25 KV	"SOFT" RAYS OF LOW PENETRATING POWER

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explosives. The primary energy conversion mode is through the Mobility Subsystem and is essentially nonhazardous. Smaller amounts of energy are converted into RF, IR, and visible light energy in addition to being dissipated as heat within the various subsystems. The area of major concern during lunar operations is the relatively high temperature (600°F) of the Radioisotope Thermoelectric Generator (RTG) radiator surfaces.

4.5.2 Batteries

Two 60-VDC, silver-zinc batteries provide the main energy source for the manned mobility mission. Of the 1494 w-hr of energy used per manned sortie, 1057 w-hr are applied through the mobility controller to the six TDMs and the four SDMs and are dissipated into the lunar surface or into the vehicle braking system. The remainder of the energy powers the astrionics equipment and science instruments.

A smaller battery (80 w-hr) of similar characteristics provides sufficient mobility power to maneuver the forward section of the vehicle into position for coupling with the rear section after these sections are deployed from the LM. This battery is not rechargeable or used after deployment.

4.5.3 Radioisotope Thermoelectric Generator (RTG) and Remote Geophysical Monitors (RGMs)

Two Isotope Heat Sources (IHS) in the RTG provide a continuous output of up to 1000 w of heat, a portion of which is converted by thermoelectric effect into 130 to 160 w at 28 VDC of electric power. The remainder is rejected from approximately 1000 cm^2 of radiating surface on the top and rear faces of the RTG. A shorting device is provided to reduce heat rejection prior to deployment on the lunar surface. Each IHS also emits up to 3.6×10^7 neutrons per second ($E \leq 0.5$ Mev).

The electrical output of the RTG is applied to the 28-VDC bus where it is made available to the various subsystems and the surplus converted to 60 VDC for recharging the batteries. There are no unique hazards involved in the conversion and distribution of the electrical energy.

Heat rejection requirements results in an RTG radiator operating temperature of approximately 600°F. Therefore, cooling is required to maintain surface temperatures within the Spacecraft Launch Adapter (SLA) below 300°F prior to launch to minimize the danger of ignition of leaking hypergolic propellants or thermal degradation of other equipment in LM Quadrant IV.

Two RGMs, each containing an RTG type IHS and rejecting approximately 600 w in heat, are included in the remote configuration of the vehicle and are transported to the lunar surface within the LM descent stage. These radiator surfaces attain a temperature of approximately 360°F and the cooling provisions discussed above apply.

It is expected that, as a result of prelaunch cooling, heat rejection into the SLA during the period subsequent to launch but prior to SLA jettison will not be critical. However, future hazard reduction analysis will require analytical verification of this assumption as well as the determination of the effect of delayed SLA jettison on mission safety.

Proper orientation of the RTG and the RGMs within the LM will permit unobstructed radiation of heat into space after the SLA is jettisoned. After deployment of the vehicle, tasks which may bring the astronauts into the vicinity of the RTG should be avoided or minimized. In particular, the effect of the rejected raditor heat on the integrity of the Extravehicular Mobility Unit (EMU) requires investigation. The structural integrity of the helmet faceplate becomes degraded at 250°F, for example, and it must be determined whether or not a set of conditions (time vs. distance) exist which would permit this to occur on the lunar surface. Momentary inadvertent contact with the Pressure Garment Assembly (PGA) or the EMU gloves may not be as serious but bears investigation.

In terms of total dose received vs. mission allowable, the radiation characteristics of the RTG and RGMs cannot be considered hazardous. Preliminary calculations for total dose received over a nominal mission timeline indicates something less than 2 rem (Table 4.11-1 in Section 4.11). Although 2 rem is still a small number compared to the mission allowable dose of 25 rem, it is recommended that this analysis be performed and that every opportunity be taken, commensurate with other mission objectives, to minimize the dose in the interest of the long-term effect on the careers of the individual astronauts.

A more detailed discussion of the RTG thermal control and the RTG radiation hazard and techniques for its control is contained in the Power Subsystem description, Vol III, Book 5.

4.5.4 Electrical Power Distribution

Power is distributed from the 60- and 28-VDC buses in a conventional manner with circuit breaker protection provided as appropriate. All wiring and junctions are protected from inadvertent contact by personnel. No requirement is expected to make or break hot connections on the lunar surface.

4.5.5 Communications Subsystem

A portion of the energy consumed by the Communications Subsystem is emitted from the S-Band steerable antenna as a coherent beam of RF energy. The characteristics of this beam are almost identical to the LM S-Band antenna in that essentially the same antenna is used and the radiated power is essentially of the same magnitude. Calculations indicate that the energy distribution in the near field of the antenna average 4.5 milliwatts/cm^2 which compares favorably with the industry and USAF accepted Threshold Limit Value (TLV) of 10 mw/cm^2. LM test data are known to have produced even lower values. The energy emitted by the S-Band steerable antenna is therefore considered to be nonhazardous.

4.5.6 Hazard Avoidance and Detection Subsystem

A portion of the energy consumed by the Hazard Avoidance and Detection Subsystem is emitted by the IR scanner as a beam of IR energy so highly coherent (0.6-minute angle of dispersion) that, for purposes of safety analysis, it may be considered as laser energy. The peak power is calculated to be 10.7×10^{-9} joule/pulse/cm^2 which is less than the accepted TLV of 10^{-8} joule/pulse/cm^2. The average power, however, is calculated to be 59×10^{-5} w/cm^2 which is in excess of the TLV of 1×10^{-5} w/cm^2. As the IR scanner is active only during the unmanned mode of lunar operations, it is not a normal hazard to be experienced by the astronauts. However, it is physically possible for the astronaut to "see" the intermediate range aperture and a determination should be made as to whether or not the EV visor will provide adequate protection (it is believed that it will). If not, a caution signal to advise the astronauts when the scanner is operative should be considered. Adequate safeguards must also be provided to protect ground personnel during scanner ground tests.

4.5.7 Diffractometer/Spectrometer

The Diffractometer/Spectrometer utilizes a 25-kv X-ray source to irradiate samples for spectrographic analysis. The characteristically "soft" X-ray produced by this source has low penetrating power and effective shielding is normally provided by the material of the compartment or container in which it is operated. The hazardous condition to be controlled, then, would be operation during test or checkout in a partially disassembled condition by unwary personnel. There should be no astronaut-associated hazards during lunar operation. Additional analysis will be required to verify radiation characteristics as this device becomes better defined.

4.5.8 TDM Remote Decoupling Devices

Pneumatically operated decoupling devices have been defined as a requirement to permit remote decoupling of individual TDMs. The design of these decoupling devices has not progressed to the point where they can be adequately assessed for safety. However, they are expected to have a very low value of potential energy and not be a hazard during lunar operations.

4.5.9 Preloaded Springs

Energy may be expected to be stored in small amounts in the unloading booms and several devices within the vehicle. The only devices defined to the point that they may be further discussed from the safety standpoint are the suspension arm extension springs which provide the energy required to unfold and lock the suspension arms during the deployment sequence. Although the energies of these springs have not been calculated, it appears as though they represent a very low order hazard during the ground sequences of folding and storing in the LM. They do not represent a hazard during lunar deployment as neither astronaut is required to be near the booms or suspension arms during the deployment sequence.

4.6 ENVIRONMENTAL CONSTRAINTS

4.6.1 Introduction

A safety review of DLRV environmental considerations, i.e., the various external influences under which the DLRV must endure or perform, reveals no new conditions which have not been fully considered in lunar vehicle design for the past several years. It does re-emphasize the desirability of evaluating new information as it becomes available from the Apollo lunar missions.

The safety review considered four major environmental regimes—earth, launch, space, and lunar surface—and is summarized in Table 4.6-1.

4.6.2 Earth Environment

Earth environment includes all environmental considerations from the manufacture of the vehicle to the point of booster engine ignition. The prelaunch environmental requirements for Apollo flight hardware are well established and conformance to them is a matter of routine technology; therefore, they will not be discussed further.

TABLE 4.6-1

ENVIRONMENTAL CONSTRAINTS

7455-191R

ENVIRONMENT	CONSTRAINT	PROBLEM
EARTH	GRAVITATIONAL FIELD	FRAGILITY OF 1/6 G STRUCTURE IN 1 G FIELD
LAUNCH	ACCELERATION VIBRATION	ROUTINE-RELIABLE DESIGN DATA & VALIDATION TECHNIQUES
	PRESSURE GRADIENT	ADEQUATE VENTING OR PRESSURE INTEGRITY OF CAVITIES
SPACE	METEOROIDS	PENETRATION OF LIFE SUPPORT ENVELOPE EROSION OF SURFACES
	NATURAL RADIATION	ROUTINE-ADEQUATE CONTROLS REQUIRED TO MINIMIZE AFFECTS OF LONG TERM EXPOSURE
	SOLAR FLARE ACTIVITY	EMERGENCY CONDITION
LUNAR	SURFACE CHARACTERISTICS	CRASH AND ENTRAPMENT HAZARDS
	SOIL PROPERTIES	AFFECTS PERFORMANCE & HAZARD NEGOTIATION CAPABILITY
	DUST	AFFECTS THERMAL CONTROL, WEAR CHARACTERISTICS, CREW TASK PERFORMANCE
	LIGHTING	AFFECTS HAZARD DETECTION CAPABILITY, DEPTH PERCEPTION, ETC.
	GRAVITATIONAL FIELD	AFFECTS VEHICLE PERFORMANCE & DYNAMIC STABILITY

The one earth environmental hazard that is of particular significance to the DLRV is the earth's gravitational field. Being designed for use within the lunar gravitational field and being strictly weight limited, the DLRV will be earth-fragile and subject to damage on every occasion that it is handled. Approaches to the reduction of this hazard are minimization of flight vehicle handling, carefully designed handling and support fixtures, validation of handling and stowage procedures on nonflight hardware, and careful selection and training of personnel engaged in these activities.

4.6.3 Launch Environment

Applicable LM-induced acceleration and vibration requirements have been specified and their incorporation into the design will be verified in the test program. Special attention should be given during flight preparations to the validation of tiedown and stowage provisions for items not integral to the vehicle.

Rapid traverse of the earth atmospheric pressure gradient during launch requires the venting of all cavitites in which entrapped gases could cause problems. Careful attention to design detail is mandatory in this respect, as adequate verification cannot be made prior to flight.

4.6.4 Space Environment

Considered here are those environmental hazards which exist beyond the earth's atmosphere but which are not unique to the lunar surface.

Meteoroid phenomena may be considered from two aspects: catastrophic disabling of the vehicles and erosion of surfaces designed for high thermal emittance. In the first case it is obvious that no special meteoroid protection is possible within the vehicle's weight and configuration constraints. It is also obvious that the operational risk involved is no greater than for a puncture of the EMU and that the same risk philosophy should apply. In the second case it has been noted that Surveyor and EASEP thermal control systems performed on the lunar surface for several months without noticeable degradation, indicating that significant micrometeoroid erosion will not occur over the design mission life of the DLRV. Additional data should be obtained from the investigation of Surveyor III parts returned on Apollo 12 and from ALSEP operation.

Natural radiation (other than solar flare activity) has been demonstrated to be inconsequential for the duration of an Apollo lunar mission. (See Section 4.11.)

Solar flare events are energency conditions that can occur with little or no warning and which require the immediate return of the LM crew to the Command Module (CM). Although not a DLRV design consideration, solar activity may influence radius of operation criteria as a function of maximum allowable time for an emergency return to the CM.

4.6.5 Lunar Surface Environment

The details of new lunar surface environment information from the Apollo Program has hardly begun to be disseminated, and DLRV design criteria based on deduction, hypothesis, and long-range measurements remain in effect. As the true nature of the lunar environment unfolds, a continuous process of reevaluation will be required to maintain the level of assurance now established in the standard of safety of this vehicle. General areas of interest, as discussed below, are only starting points for the detailed analytical effort that should be performed.

Useful information has been published on the dimensions and frequency distribution of readily discernible surface features such as crater slopes and rims of craters, effects, etc. It will be of great interest and possibly have an effect on the safety analysis of several subsystem designs to review similiar information on what have been surface features of a more hypothetical type, such as "crusted" voids, shear precipices, and overhanging rock formations.

Hard data resulting from the analysis of soil samples returned from the moon will aid in validating the calculations on which vehicle stability, maneuvering and braking are based. These, in turn, define the maneuvering envelope within which the vehicle may be prudently operated with an acceptable level of risk.

Dust has been a topic of particular interest since Apollo 12. Judging by crew comments and other unofficial sources, the dust encountered on that mission exhibited remarkable qualities of abrasion and adhesion. This is of great interest in evaluation of the EMU crew station interface, crew tasks requiring the mating and breaking of connections, thermal control, and the wear characteristics of all moving parts exposed to the environment.

Lunar surface lighting characteristics are of critical importance in crash safety analysis. The operator must be able to detect unnegotiable obstacles beyond the safe operating envelope of the vehicle or risk the hazard of "overdriving." Evaluations must be made on the effects of various sun angles in washing out surface features and of driving in and out of shadows to provide adequate crew briefing material.

Visual acuity, VHF propagation, and crew metabolic requirements data will provide a sound basis for the development of DLRV operating radius vs. emergency walkback criteria.

Finally, human experience will provide a degree of understanding and confidence in the adaptability of man/machine performance parameters to the lunar gravitational environment that cannot be derived from the output of a computer program. Man's adaptability to 1/6 g may be less difficult than anticipated, as witnessed by the experiences of the crews of Apollo 11 and 12. However, maneuverability and stability of the vehicle, in particular, in response to crew control inputs will require careful developmental testing and subsequent confirmation on the lunar surface before the vehicle can be considered plan-rated for maximum design performance conditions.

4.7 HAZARDOUS MATERIALS

The depth of design attained during this study has not included the specification of material requirements in all areas. However, since the vehicle would be fabricated for the most part of aerospace-qualified materials and components, the problem of hazardous materials is expected to be minimized by employing NASA-developed and specified standards.

Two known material selections with somewhat hazardous characteristics have been tentatively selected for incorporation into the DLRV and are shown in Table 4.7-1.

Beryllium dust and vapors are toxic and must be guarded against during machining operations. Finish machining of forgings by the fabricator, who controls this hazard on a routine basis, avoids the problem in the assembly area. However, positive identification by special markings or documentation is required to assure adequate control of reworked or scrapped material.

The application of the concept of phase change material (PCM) in thermal control radiations has resulted in the tentative selection of two organic substances not known to be qualified for space flight: Eicosane $CH_3\,(CH_2)_{18}\,CH_3$, and Tetracosane $CH_3\,(CH_2)_{22}\,CH_3$. These substances will apparently support combustion, but as they are now marketed only as "laboratory specialties," further analysis is required to determine their over-all characteristics and to quality them for space flight. Of particular interest would be their corrosive or other detrimental effects on the material of the honeycomb radiators into which they will be sealed.

TABLE 4.7-1

HAZARDOUS MATERIALS

7455-192-R

MATERIAL	HAZARD	EVALUATION
BERYLLIUM FORGINGS	TOXIC EFFECT (BERYLLIOSIS) WHEN INHALED AS DUST OR FUMES	FINISH MACHINING TO BE PERFORMED AT VENDOR'S FACILITY WHERE ADEQUATE PRECAUTIONS ARE IN EFFECT
EICOSANE TETRACOSANE (PHASE CHANGE MATERIALS)	MODERATELY COMBUSTIBLE - NOT APPROVED SPACECRAFT MATERIAL-MANY CHARACTER-ISTICS NOT EVALUATED	HAZARDOUS ONLY IN THE EVENT OF RUPTURE OF HONEYCOMB RADIATORS

Further development of the DLRV design resulting in material selections will be monitored to assure the maximum use of qualified materials compatible with their particular application. The use of hazardous materials, when required by legitimate design considerations, will be justified on an individual basis including assessment of the process control or operational use precautions which are to be implemented.

4.8 CRASH SAFETY

In considering a rationale for crash safety, the two extremes of possible design approaches are: (1) a design which is optimized to reduce the probability of a crash situation to an acceptable level of risk and which requires no special crash protection; and (2) a design which assumes that the probability of a crash situation cannot be reduced to an acceptable level of risk and in which all other requirements are traded off to assure crew survival under all hypothesized combinations of adverse circumstances.

Bendix has chosen to concentrate on a vehicle design having the highest possible degree of inherent crash safety which may be operated with reasonable prudence by an astronaut without weight or performance degrading devices.

Two basic crash conditions may be considered in an evaluation of DLRV crash safety:

1. Impact - Failure to detect and avoid unnegotiable obstacles resulting in contact with sufficient force to damage the vehicle or crew

2. Turnover - Separation from the lunar surface at an attitude which does not permit recovery to a normal, statically stable driving condition.

An impact crash could result from failure to avoid unnegotiable obstacles such as boulders and crevasses because of the failure or inability of the operator (astronaut or earth control) to perceive and evaluate the obstacle in sufficient time to reach and take necessary corrective action. Different sets of conditions establish the ability to detect hazardous objects and the ability to take effective action to avoid them. These conditions, varying continuously with changes in the lunar surface environment and operator driving inputs, are interdependent in establishing safe operating conditions. As long as the hazard detection distance extends beyond the distance required to turn or brake effectively to avoid the obstacle, a safe driving condition exists. When it is less than the required maneuvering distance, the vehicle is being overdriven and a dangerous condition exists.

Detection capability depends in part upon the ability of the operator to see out beyond any intervening vehicle structure in order to perceive and evaluate lunar surface features. A clear LOS is a matter of vehicle design; crew station location and minimizing glare or dust plume producing surfaces which could unexpectedly degrade vision at a critical moment. In the Bendix DLRV the crew station is at the forward end of the main chassis between the front wheels and with no intervening structure other than the control panel, which blocks a non-critical cone of vision downward and to the right. The areas of contact with the lunar surface for both wheels are visible for cautious slow speed negotiation of all obstacles. Thus, the forward LOS, for all practical purposes, is unobstructed.

There are no known published data relative to visual acuity on the lunar surface as a function of lighting conditions. However, it has been noted that surface features tend to "burn out" and are not readily distinguishable in the shadowless lighting resulting from high sun angles. Failure to recognize these conditions and to reduce speed accordingly could result in hazardous overdriving.

It has been estimated that, under more nominal light conditions, obstacles may be detected up to at least 100 ft from the DLRV crew station (Section 4.4). Comparing this to the steering and braking limitations discussed in Sections 4.9 and 4.10, it appears that the vehicle can be safely driven at maximum speed on a smooth mare, subject to verification as more definitive lunar surface environmental data are published.

A turnover could result from exceeding the static stability limits of the vehicle such as: in attempting to negotiate an excessively steep slope, from a condition of dynamic instability induced by speed and lunar surface profile characteristics, or as the result of an impact crash.

The first two conditions are a function of local lunar surface features and should be recognizable by the operator as incipient emergency situations in time to reduce speed or choose a more favorable course. Being inherently very stable, the vehicle provides a considerable margin of judgment in this respect; however, to provide an extra margin of safety, a stability warning computer automatically limits vehicle speed as a function of lunar surface conditions and provides an audio/visual warning when safe stability limits are being exceeded.

The problem of DLRV detection and avoidance of lunar surface obstacle hazards in the unmanned mode was exhaustively analysed during the Phase B Study under Task 3; these details are documented in Vol III, Book 3. An excerpt of the scope and results of this study and the related TV and remote control studies is also included in Section 4.18. In addition to the attention placed on design to avoid obstacles in the unmanned mode, the effects of possible crashes at remote control speeds were investigated. It has been determined that a fully loaded DLRV may impact an unyielding obstacle at speeds up to 2 km/hr and absorb all the impact energy in a single wheel without damage to the wheel or its suspension. Thus, the consequences of obstacle crashes in the unmanned mode are not as severe as in the manned mode. Either form of a hazard encounter, however, is capable of causing system failure and must be accounted for in the Hazard Detection and Avoidance Subsystem.

4.9 DLRV STEERING AND MANEUVERABILITY

The six-wheel DLRV configuration is steered by double-Ackermann (four wheel) front and rear wheel steering. Computer steering analysis has been performed for the fully loaded vehicle on both level and side slope surfaces with the vehicle traveling at various speeds and moving straight ahead just prior to initiating the turn. For each run the wheels were turned at a 20°/sec rate until the wheels reached 29° stops on the inside wheels and 16° stops on the outside wheels. The vehicle steering was analyzed for steering characteristics over a speed range of 2 to 16 km/hr.

Figure 4.9-1 shows the effects of speed in turning on a level surface having a 0.6 coefficient of friction. Using the data from Figure 4.9-1, it can be seen that, at 16 km/hr, the astronaut driver must initiate a turn slightly more than 13 m ahead of a rock or other obstacle if he needs to translate the vehicle path by 2 m to avoid the obstacle. This compares with 11.0-m straight line stopping distance required to avoid impacting the obstacle (see Section 4.10). Section 4.4 indicates that the astronaut should have little difficulty in seeing minor obstacles at or beyond 30 m; however, the driver's reaction time must be considered in addition to the turn or stop action to avoid the obstacle. At 16 km/hr, the driver has 17 m of travel between a 30-m recognition distance and the 13-m point ahead of obstacle at which he must decide if he will initiate a turn. This 17-m distance represents a travel or a reaction time of nearly 4 sec which should provide ample margin for better judgment of the obstacle and initiating a steering maneuver for avoidance. If the driver desires to change his path more than 2 m to avoid an obstacle within a recognition distance of 20 m at 16 km/hr, stopping or reducing speeds for greater maneuverability would appear to be advisable.

Additional steering distances must be allowed for steering on side slopes or down slopes. Figure 4.9-2 illustrates the effects of speed in turning on various downhill slopes at a 4-km/hr speed.

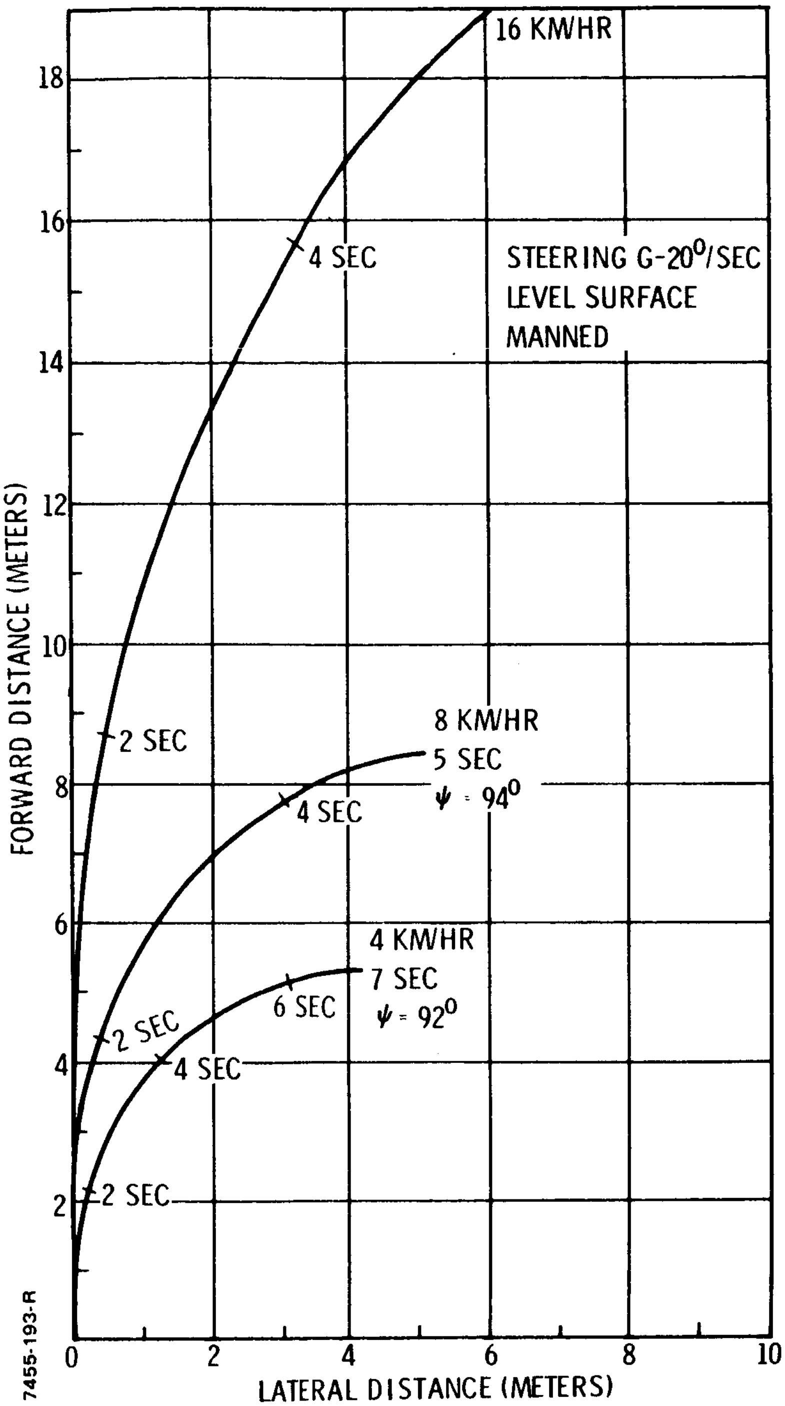

Figure 4.9-1 Steering Paths on Level Surface

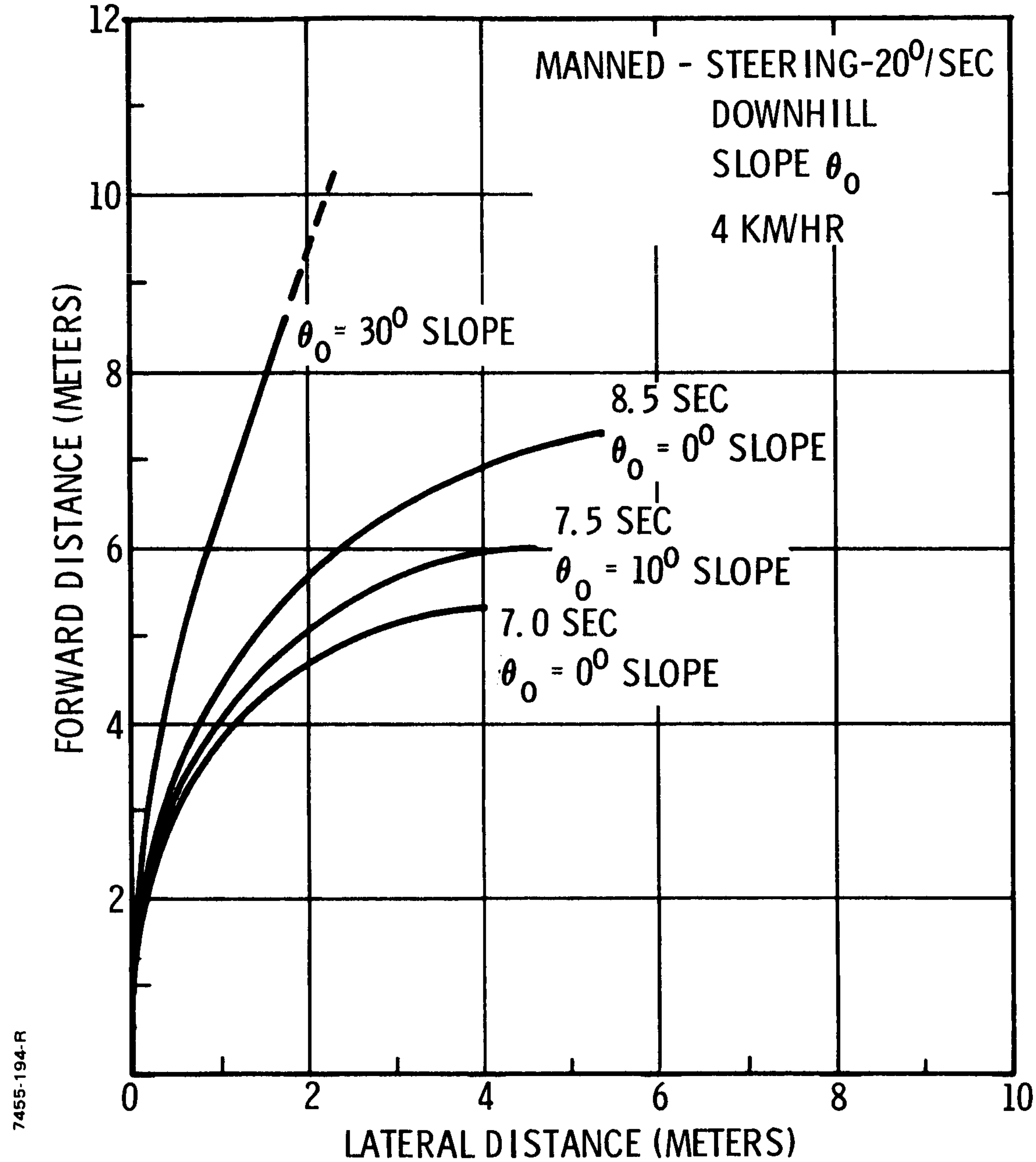

Figure 4.9-2 Steering Paths - 4 km/hr Downhill

For unmanned mode operation, the 4-km/hr turning rate data represent a worst-case situation. At speeds between 0.5 and 2.0 km/hr, which are more typical operating speeds in the unmanned mode, the forward distance for obstacle avoidance on slopes up to 30° will always be below 5.5 m. Medium-range hazard detection sensors operating beyond 10 m, combined with hazard detection logic, are capable of providing for automatic turn or stopping control with 100% margin if desired. These aspects of hazard detection and avoidance are detailed more fully in the Task E study report, Vol III, Book 3.

4.10 ACCELERATION AND BRAKING

The acceleration capability of the vehicle depends on the torque capabilities of the traction drive and the wheel surface interface characteristics. Acceleration may be readily controlled by the astronaut driver by use of the continuously variable speed control and selection of transmission high or low gear ratio.

The vehicle's maximum deceleration characteristics are primarily dependent on the friction between the wheels and the lunar surface. Table 4.10-1 illustrates the linear relationship between the initial speed of a fully loaded vehicle and the stopping distance for level conditions of the hard and soft lunar surface.

TABLE 4.10-1

VEHICLE DECELERATION ON A LEVEL SURFACE

Initial Speed (km/hr)	Stopping Distance (m) Hard Surface, Soft Soil		
	$\mu = 0.7$	$\mu = 0.6$	$\mu = 0.5$
2	0.15	0.18	0.21
4	0.58	0.70	0.82
8	2.3	2.8	3.3
12	5.2	6.2	7.3
16	4.1	11.0	12.8

7456-DA

The astronaut hand control on the DLRV provides continuously variable reduction of vehicle speed of the TDM units for electrodynamic braking, supplemented by motor reversal (plugging), and conventional automotive braking at the lowest speeds. Maximum deceleration is achieved without skidding; therefore, the astronaut must exercise caution, feel, and visual observation of the front wheels to assure that the wheel rotation is reduced at a rate compatible with vehicle deceleration. Brief astronaut training during the first sortie deployment checkout run may be required to optimize astronaut effectiveness under the low lunar gravity conditions.

The time or distance required to stop from the low remote operating speeds is less critical than that time required to detect hazards and process stop commands through MCC. As noted in Table 4.10-1, the vehicle may be brought to a stop from 4 km/hr in less than a meter and with relative insensitivity to control application technique.

4.11 RADIOISOTOPE SOURCE RADIATION HAZARDS

The tissue equivalent dose rate from the four radioisotope fuel capsules used in the DLRV (RTG = 2, RGM = 1 each) is specified not to exceed 70 millirem/hour/capsule at a distance of 1 m in any direction. Considering the location of each of these sources during a nominal lunar mission relative to the position of the crew, an upper limit approximation was calculated on the total mission dose received. Conservatism in this estimate results from: the fact that dose rates for various mission segments were calculated only as a function of distance without allowance for the shielding effects of the LM or other hardware, the assumption that the DLRV is operated continuously during each EVA by the same astronaut, and that the DLRV is parked within 25 ft of the LM during rest periods.

The incremental and total doses calculated using these assumptions are presented in Table 4.11-1. Note that the first two mission segments considered could be reduced considerably by factoring in the shielding effects of the CM and SM. All told, it is felt that a mission dose budget of 1 rem is attainable by using reasonable care in the planning of EVA activities and in the efficient design of "clean" fuel capsules.

Table 4.11-2 presents information on permissible radiation levels. The wide range of values noted in the literature prompted an inquiry to the Radiation Constraints Panel at the MSC for criteria actually used in Apollo mission planning. The 5-cm penetration allowable dose of 25 rem was apparently established with some concern as to its biological effects and should be approached cautiously. Billingham, previously quoted during this study, is apparently out of date. DH 1-6 standards are closest to Apollo mission experience to date and are probably most meaningful from a system design viewpoint. The DLRV, as specified, is capable of meeting these standards.

4.12 UNLOADING, DEPLOYMENT, AND CHECKOUT CONSIDERATIONS

The mechanical/thermal aspects of the DLRV Tiedown and Unloading (TDU) Subsystem provide the only interface between the LM and the DLRV. There are no power or other electrical interfaces for the manually deployed configuration.

TABLE 4.11-1

MISSION REDUCTION DOSAGE (ATTRIBUTABLE TO DLRV)

CONDITION	TIME (HR)	DOSE RATE (MREM/HR)	DOSE
CREW IN CM, STACKED	7:00	2	14
CREW IN CM, DOCKED	97:00	7	679
CREW IN LM	15:00	22	330
DLRV DEPLOYMENT	0:30	100	50
SORTIES	14:40	40	587
REST PERIODS @25'	34:00	5	170
LOAD RGM'S	0:30	100	50
		TOTAL	1780 MREM

7455-195-R

NOTE: EFFECT OF SPACECRAFT SHIELDING NOT CONSIDERED

TABLE 4.11-2

ALLOWABLE MISSION RADIATION DOSE

7455-198-R

IONIZING RADIATION OF ANY TYPE OR COMBINATION OF TYPES	PERMISSIBLE REM* PER CALENDAR QUARTER PER AFSC DH 1-6**	PERMISSIBLE REM PER APOLLO MISSION PER RADIATION CONSTRAINT	PERMISSIBLE REM PER APOLLO MISSION PER BILLINGHAM (NASA-SP-71)
WHOLE BODY	1.25	---	1600
HEAD, TRUNK, BLOOD-FORMING ORGANS, EYE LENS AND GONADS	1.25	25	270
BODY EXTREMITIES	18.75	---	4000
SKIN	7.50	200	----
ACUTE ACCIDENTAL SINGLE EXPOSURE (EITHER INTERNAL OR EXTERNAL TO THE BODY)	25.0	50/400	----

*REM=ROENTGEN EQUIVALENT(S), MAN

** IF A MEDICAL RECORD IS AVAILABLE, A HIGHER EXPOSURE (80% OF THE LIMIT IN EFFECT) IS PERMISSIBLE; 3/REM/QUARTER, PROVIDED NO MORE THAN $5(N^{-18})$ REM TOTAL ACCUMULATED DOSAGE HAS BEEN MET (WHERE N IS THE AGE OF THE SUBJECT)

TARGET DOSE RATE TO ASSURE FULL ACTIVE CAREER FOR ASTRONAUTS DURING ERA OF LONG DURATION MISSION = .15 REM/DAY

The basic concept features a three-point tiedown for the forward four-wheel section in LM Quadrant I and a similar three-point tiedown for the aft two-wheel section in Quadrant IV at hardpoints specified by the LM contractor. Structural safety of the LM is assured by having the vehicle mass at the cg location within the interface constraints specified for LM.

The tiedown releases incorporate ball-locked pull pins actuated by cables. Hangup of the tiedown releases is prevented by the use of thin-walled glass-backed teflon bushings and qualified dry lubricants used at the separating surfaces to achieve redundant safeguards against fretting and cold welding of the pivots and the release pins.

Astronaut visibility of the unloading and avoidance of the area beneath the unloading operation are achieved by locating the astronaut on the LM ladder with three winch cranks to perform most of the release, unloading, and deployment sequence. The three cranks are used to sequentially peel away thermal blankets over the vehicle sections, lower the sections on booms, and deploy vehicle wheels in the process of lowering to the lunar surface. From a fixed point on the LM ladder, these operations are easily performed in the same manner regardless of the LM attitude or lunar surface variation beneath the DLRV. Maximum cranking loads are 5-lb forces on the 5-in. radius winch cranks. Worm and spur gear reductions in the cranks also eliminate backlash or inadvertent loss of crank control during astronaut operation.

The aft (two-wheel) section with the RTG mounted on it is stowed with the RTG facing outward to eliminate excessive inward heat loads on the LM bulkhead. After the fore and aft sections of the DLRV are lowered to the lunar surface, simple lanyards are used to release the sections from lowering booms. A special 80 w-hr deployment battery is provided to allow the astronaut to drive the fore section to the aft section and avoid pulling an unpowered section. The use of a long electrical cable was considered but was ruled out because of the additional weight and the hazards of astronaut and vehicle entanglement.

A preliminary task timeline analysis of the DLRV unloading, deployment, and checkout has been performed, and the major events are illustrated in Table 4.12-1. Important safety considerations are reflected in the over-all timeline including: (1) early erection of the TV to allow MCC monitoring of operations, (2) visual inspections and checkout coordination with MCC throughout the operations, and (3) test driving by the astronaut to ensure that the man and machine are properly integrated under lunar gravity conditions before the DLRV sorties are initiated.

TABLE 4.12-1

UNLOAD AND DEPLOYMENT/CHECKOUT—MAJOR TASKS

7183-88-S

TIME			MAJOR EVENTS	
HR	MIN	SEC		
00	02	00	1.0	EGRESS FROM LM, ACTUATE MESA RELEASE
00	02	45	2.0	DLRV FRONT SECTION REMOVAL
00	05	00	3.0	DEPLOY TV CAMERA
00	08	00	4.0	CHECKOUT LM, TAKE PICTURES, REST
00	02	15	5.0	DLRV REAR SECTION REMOVAL
00	04	25	6.0	DEPLOY CREW STATION
00	00	30	7.0	INGRESS DLRV FRONT SECTION
00	03	00	8.0	VISUAL INSPECTION, CHECKOUT C & D, MONITOR STATUS WITH MCC
00	02	00	9.0	CHECKOUT FWD, REV, HIGH AND LOW GEARS, STEERING AND BRAKE SYSTEMS
00	01	00	10.0	DRIVE FRONT SECTION TO A POSITION FORWARD OF DEPLOYED REAR SECTION OF DLRV
00	00	30	11.0	EGRESS DLRV
00	01	00	12.0	MECHANICALLY COUPLE REAR SECTION TO FRONT SECTION AND LOCK
00	00	30	13.0	ELECTRICALLY COUPLE FRONT AND REAR ASTRO CONNECTORS
00	00	30	14.0	INGRESS DLRV
00	03	00	15.0	CHECKOUT C & D, TURN ON RTG, CHECK ALL STATUS WITH MCC
00	00	30	16.0	EGRESS DLRV
00	05	00	17.0	REMOVE SCIENCE PACKAGES FROM LM/SEQ BAY, TRANSFER AND STOW EQUIPMENT ON DLRV
00	00	40	18.0	VISUAL WALK-A-ROUND INSPECTION OF DLRV FOR MECHANICAL AND/OR THERMAL (DUST, ETC.) DEGRADATION
00	00	30	19.0	INGRESS DLRV
00	01	00	20.0	DRIVE TEST COURSE, CHECK ALL VEHICLE STATUS WITH MCC
00	00	30	21.0	EGRESS DLRV

7183-88-S

44 MIN, 35 SEC TOTAL TIME

The potentially difficult fore to aft section mating operation is divided into a simple vehicle-centered straight mechanical slip-in connection and a convenient side access of the power to auxiliary panel set of connections. The electrical mating connectors are made with nonenergized contacts.

Possible astronaut errors during the DLRV deployment sequence are minimized by the use of deployment winches which actuate all the tiedown release and unloading maneuvers until the vehicle sections are safely down on the lunar surface. Television monitoring provisions by MCC during deployment and check-out will aid the astronaut in the avoidance of errors.

Comprehensive telemetry functional status and housekeeping measurements on the DLRV allow MCC to fully assess DLRV checkout status during initial checkouts and during astronaut checkout driving tests.

4.13 MANNED-TO-UNMANNED CONVERSION CONSIDERATIONS

Earth installation of the RTG and its fuel capsule on the aft section of the DLRV precludes any need for the astronaut to handle the vehicle RTG equipment at any time on the lunar surface.

Location of all movable science on the forward section of the DLRV virtually eliminates the need for the astronaut to work near the thermal and ionizing radiation of the aft section-mounted RTG during the manned mode operation, or during the manual conversion of science in preparation for the remote mode mission.

Table 4.13-1 illustrates the major events and activities of the astronaut during the vehicle/science conversion activity.

Safety analysis of the preliminary conversion timeline identifies the handling of RGM science packages as the most significant hazard during the conversion activity. Each RGM incorporates RTG equipment which must be handled with special tools and procedures to ensure minimizing thermal and ionizing radiation hazards.

From the vehicle safety standpoint, visual inspections, dust removal, astronaut and earth telemetry coordinated vehicle/science checkouts, and removal of the DLRV from the LM ascent stage blast or dust effects are safety considerations which have been integrated into the preliminary conversion timeline activities.

TABLE 4.13-1

MANNED TO UNMANNED CONVERSION—MAJOR TASKS

7183-87-S

TIME				MAJOR EVENTS
HR	MIN	SEC		
00	00	30	1.0	INGRESS DLRV
00	01	00	2.0	SET C & D PANEL SWITCHES TO REMOTE MODE OPERATION
00	00	30	3.0	EGRESS DLRV
00	00	10	4.0	REMOVE MANUAL DF SYSTEM AND DISCARD
00	01	00	5.0	REMOVE LSS, STAFF TRACKER AND DISCARD
00	00	20	6.0	REMOVE AHLT AND DISCARD
00	00	30	7.0	FOLD CREW STATION INTO UNMANNED MODE FOR BULK SAMPLE STORAGE
00	10	00	8.0	UNLOAD RGM'S (2) FROM LM/SEQ BAY AND TRANSFER AND ATTACH TO DLRV
00	02	00	9.0	UNLOAD HAZARD DETECT PROBES FROM LM BAY, TRANSFER AND MECHANICALLY COUPLE TO DLRV
00	00	20	10.0	ELECTRICALLY CONNECT HAZ PROBE CABLE TO DLRV
00	01	00	11.0	SET AUX PANEL SWITCHES TO REMOTE MODE OPER
00	02	00	12.0	VISUAL WALK-A-ROUND INSPECTION OF DLRV FOR MECHANICAL AND/OR THERMAL (DUST, ETC.) DEGRADATION
00	04	00	13.0	CHECK ALL REMOTE CONTROL SYSTEMS WITH MCC
00	00	10	14.0	OK MCC TO REMOVE DLRV FROM LM PROXIMITY

23 MIN, 30 SEC TOTAL TIME

4.14 CREW STATION DISPLAY AND CONTROL FUNCTIONS

The crew station display and control functions are explored in detail in Vol II, Book 1, and discussed from a failure effect and criticality viewpoint in Appendix B of this volume. Comments in this section deal only with topics of particular safety significance.

Crew station design, selection of astronaut controls and displays, and the avoidance of crew hazards have been conceived, chosen, and evaluated from the safety standpoint based on all NASA-developed astronaut capability and limitation criteria available to the study program. (These criteria are summarized in Bendix Document LTM-34, "Preliminary Crew Systems and Operation Requirements for the Lunar Roving Vehicle," published 5 July 1969.)

Previous studies have indicated the desirability of a mobility hazard computer to provide an audio/visual warning of impeding dynamic instability. A somewhat different approach, utilizing on-board computing capability required for the remote mode of operation, is used on the DLRV. Speed and attitude data are processed and sent to the mobility controller as a speed limiting signal acting as a variable governor. This signal may also, at a selected threshold value, activate an audio/visual warning. A manual override switch on the hand controller provides an option to bypass the governor while retaining the audio/visual warning feature.

Both the hand controller and the display panel are to the right of the operator. Considering EMU mobility constraints which make it virtually impossible for the left hand to reach across to all areas of the panel, it will be necessary to perform controller and panel control functions with the right hand. Additional requirements for use of the right hand may be anticipated in assisting a passenger or in manipulating cargo items carried on the right side of the vehicle. It has been proposed that a time delay be incorporated in the safety switch circuit so that the right hand may leave the hand controller for short periods of time to perform other functions without affecting the speed or the path of the vehicle. Care must be taken, in optimizing the time delay, to provide a useful feature without providing an essentially uncontrolled mode of operation.

The basic philosophy in determining on-board control and display requirements was to relegate to the gound station all status monitoring functions and to the auxiliary control panel all non-time-critical control functions not pertinent to the immediate well-being of the astronauts. Retained are all real-time critical functions and those required to effect a safe return to the LM in the event of uplink loss.

4.15 SCIENCE INTERFACE HAZARDS

The Diffractometer/Spectrometer contains a 25-kv X-ray source which is evaluated as a potential personnel hazard in Section 4.5.

The magnetometer is planned to be extended vertically from its stowage configuration on the rear unit to a height of approximately 20 ft on an extensible boom. The boom characteristics are undefined and a safety assessment cannot be completed. However, it appears that, unless adequate stiffness is provided, physical contact with the VHF antenna or main mast may occur as a result of bending moments induced by rough surface features. In the event of fracture, the boom could strike the vehicle or astronaut, or become entangled with the vehicle so as to degrade its mobility. These conditions must be considered in establishing boom design requirements.

Four devices (two RGMs, sampler arm, gravimeter) are extended from the vehicle to the lunar surface during the remote mission. In the event they could not be retracted, serious degradation of vehicle mobility could result. Requirements for positive methods of jettisoning these devices are recognized, but specific mechanisms have not yet been defined.

The JPL and bulk sample storage boxes appear to be large for safe handling by the astronauts under EVA conditions. Further analysis of the crew task functions and task simulations should be undertaken to verify their suitability for the DLRV mission.

The Staff Tracker, like the magnetometer, is a vertically mounted package considered for use during the manned mode. Further investigation of the mounting design during the development phase is suggested to assure that the 25-lb unit will not fall on the crew or other vehicle-mounted equipment during vehicle operations.

The possible use of active seismic experiments on the DLRV is a potential ordnance hazard which has not been investigated for lack of experiment definition.

The possibility of science or other DLRV-borne equipment coming loose during astronaut driving may be prevented by the use of multiple fastening techniques or latch and pin techniques suggested by the study but subject to further design and evaluation during development.

4.16 DLRV MAGNETIC CLEANLINESS

The primary sources of RF and EMI fields were investigated as part of the science interface studies of DLRV compatibility with the Magnetometer Experiment. These same sources represent the primary sources of RFI/EMI with regard to the LM and astronaut communications. The major items of concern are:

Assembly	Components
Traction Drive	Permanent magnet motors
Steering Drive	Permanent magnet motors
RTG and Power Cable	Generator assembly
Transmitter	Amplitron
Antenna	Diplexer
Miscellaneous	Switches, transformers, cable, and wiring

The Transmitter, RTG, TDMs, and antennas were determined to be the most significant EMI energy sources; however, development phase testing of actual early prototype equipment and the selected packaging techniques are recommended to establish the realistic measure of EMI characteristics hazardous to communication and science interfaces.

System, subsystem, and packaging variations to minimize EMI may effectively proceed only from the point of initial testing of the intended designs after the following general considerations are applied to the degree practical:

1. At the parts level, the relative magnetization of switches, transformers, on down to transistors, connectors, and capacitors should be considered in their selection.

2. In the materials area, nonferrous alloys, such as aluminum, magnesium, and titanium alloys, are preferred to iron and nickel alloys.

3. Proper wiring practice can reduce the stray magnetic fields by minimizing the effective area of current loops, the number of turns, and current, and by loop orientation and compensation techniques.

4. The magnetic history, including previous magnetic exposure, heat treatment, mechanical treatment, and temperature, affect the permanent magnetization of the system and its components.

5. Degaussing in a high field helps to reduce the level of magnetic field.

6. Shielding as necessary should be grounded at both ends if required for long lengths of continuous wire.

7. Double or triple shielding of wire may be required to reduce the EMI of the wire.

8. When cable shields are routed through connectors, the individual shields should be carried through separate pins.

9. Signal returns, power returns, and chassis grounds should be isolated from each other.

10. Return paths should be grounded only at predetermined and specified common points to eliminate ground loops and minimize EMI.

4.17 BATTERY SAFETY CONSIDERATIONS

Hazardous conditions which could result from the DLRV batteries are of two general kinds: internal shorting of individual cells and excessive charge or discharge rates.

Internal shorting is usually the result of a separator failure between the positive and negative electrodes of a cell. In high-quality spacecraft batteries, a cell failure is most likely to occur during or shortly after the forming of the charge as the result of an undetected manufacturing defect. Having survived this period successfully, the probability of the battery completing its design duty cycle satisfactorily is very high.

Excessive charge or discharge of a battery can result in evolvement of oxygen or hydrogen or both, depending on the circumstances. In a vented silver-zinc battery, as used on the DLRV, the amount of gases vented would probably be insufficient to be considered a hazard and would be of less interest than the effect on the reliability of the battery.

Once the batteries are formed and installed in the DLRV, their internal temperatures are monitored until several hours prior to launch when the monitoring instrumentation must be cleared away. The assumption is made that if the batteries have survived a wet-stand period of two or three days without developing internal shorts, they will continue through the mission duty cycle without difficulty. This approach obviates the requirements to integrate the monitoring instrumentation into the LM or Instrumentation Unit (IU) data downlinks.

Once spaceborne, the most serious result of an internal short would be rupturing of a battery cell and case, thereby dumping electrolyte into the thermal control compartment. This damage from the caustic electrolyte would be confined to the DLRV. If the short occurs on the lunar surface, it would limit the EVA traverses to walk-back range as long as one battery continued to function adequately.

Preliminary specifications for the potential lunar vehicle battery suppliers have considered the inherent hazards of these energy sources. These specifications include applicable provisions for comprehensive battery design hazards analyses, development evaluation tests, and proof testing to assure that all foreseeable hazards are minimized.

4.18 REMOTE CONTROL OPERATIONAL SAFETY

DLRV Phase B study tasks which included important consideration of vehicle safety for the remote control operation were:

1. Task E - "Hazard Detection and Avoidance Subsystem Design and Analysis." The over-all results are detailed in Vol III, Book 3.

2. Task F - "Control Subsystem Design and Analysis." The over-all results are detailed in Vol III, Book 4.

3. Task H - "Ground Support Equipment Definition." The over-all results are detailed in Vol III, Book 5.

The Task E (hazard detection and avoidance) study encompassed: (1) analysis and definition of lunar surface feature hazards, (2) requirements for hazard detection sensors, (3) analysis of TV capabilities and limitations for hazard detection, (4) design of IR radar sensors to supplement TV for hazard detection, (5) design of vehicle-borne hazard detection subsystem logic to automatically stop or turn the vehicle in the event of impending encounter with an unnegotiable hazard, and (6) design of DLRV hazard detection logic for vehicle dynamic stability warning or speed limit control during the manned mode of operation. Individual and combination lunar surface hazards were defined as consisting of the following: (1) slopes > 35° > one vehicle length, (2) rocks > 30 cm (wheel hub clearance), (3) crevasses > 8 cm normal to vehicle path, (4) loose soil > 30 cm in depth, and (5) fragile crusts > 80 cm across with bearing strength < 0.5 $lb/in.^2$.

The design and evaluation of the TV, IR Hazard Radar, Hazard Detection computer functions, and dynamic stability warning logic are presented as part of Vol III, Book 3. From a safety standpoint, the capabilities and limitations of these equipments are considered preliminary theoretical judgments which should be subjected to extensive development phase simulation tests before positive conclusions are stated for detection equipment limitations and redline conditions for the vehicle operation using the proposed hazard detection equipment.

The Task F (control subsystem design and analysis) study encompassed: (1) earth-moon communication/data-handling time delays for effect on safe control of the vehicle in continuous remote driving operations, (2) use of path prediction techniques to enhance remote vehicle navigation and obstacle avoidance under communication time delay conditions, (3) TV display of remote vehicle driving including roll and pitch indication of DLRV attitude of the vehicle during traverse, (4) use of auxiliary illumination devices to enhance TV visibility for detection of hazards during remote control operation in shadowed areas, (5) ground station requirements for telemetry data and ground console display of all critical DLRV status functions, performance data, and malfunction data for normal and emergency operating conditions.

Figure 4.18-1 illustrates the vehicle limiting speed vs. system time delay. The maximum velocity for DLRV operation during the continuous remote driving mode is identified as 6.5 km/hr based on a minimum earth-moon communication loop time delay of 2.6 sec for TV data and command reaction input to the vehicle. One of the objectives of the remote control study has been to provide for system capability for speeds in excess of 2 km/hr to reduce mission time and enhance the probability of mission success. However, if reduced speeds are required for vehicle safety, the remote control continuous operation loop is capable of sustaining the 2-km/hr mission speeds with communication network processing delays or decision delays in excess of 10 sec in the vehicle-to-earth-to-vehicle reaction loop.

Figure 4.18-2 illustrates the DLRV ground station driver's TV display including features representing path prediction aids, the use of pitch and roll indicators, and a bearing indicator of course deviation from the correct navigation

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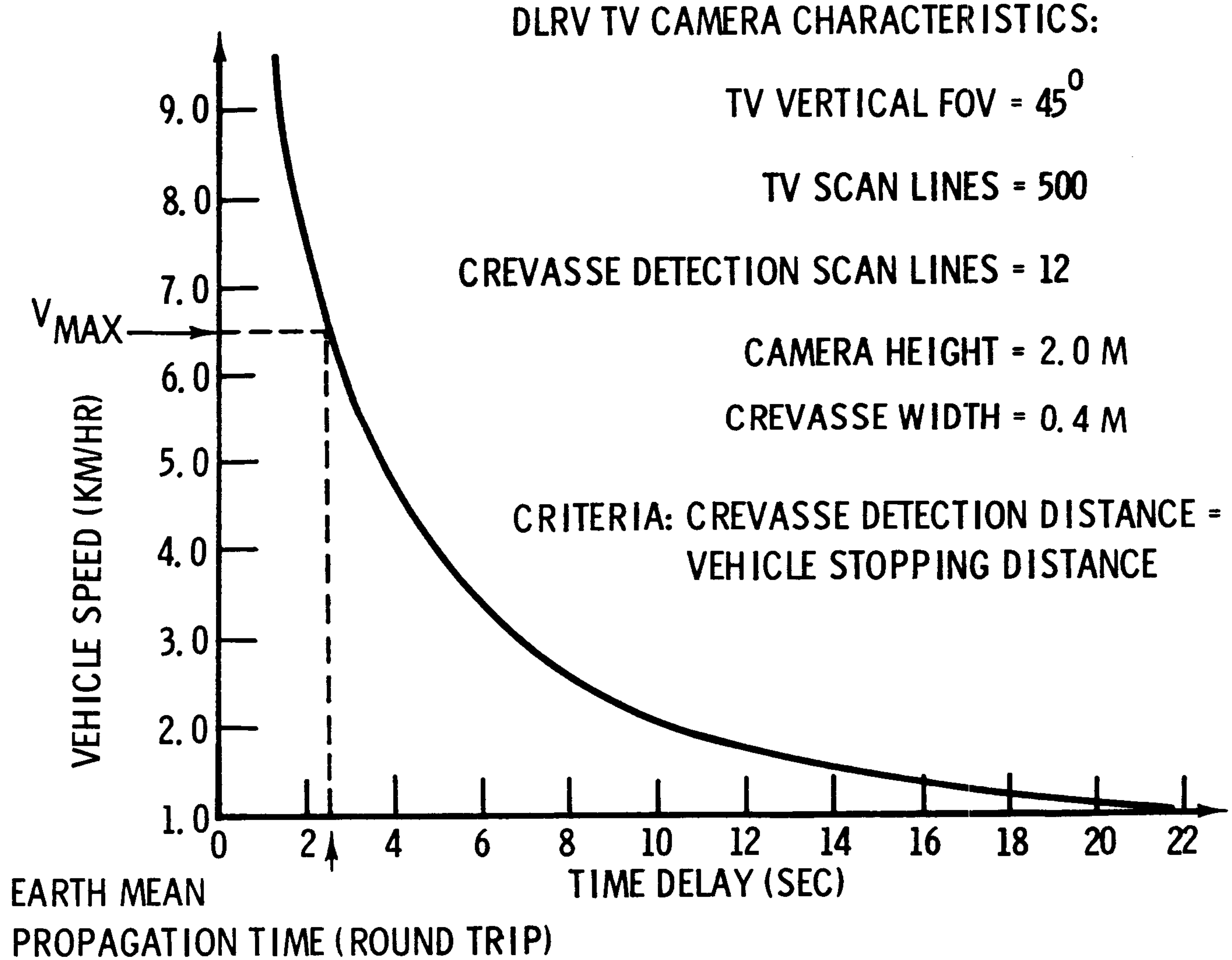

Figure 4.18-1 Vehicle Limiting Speed vs. System Time Delay

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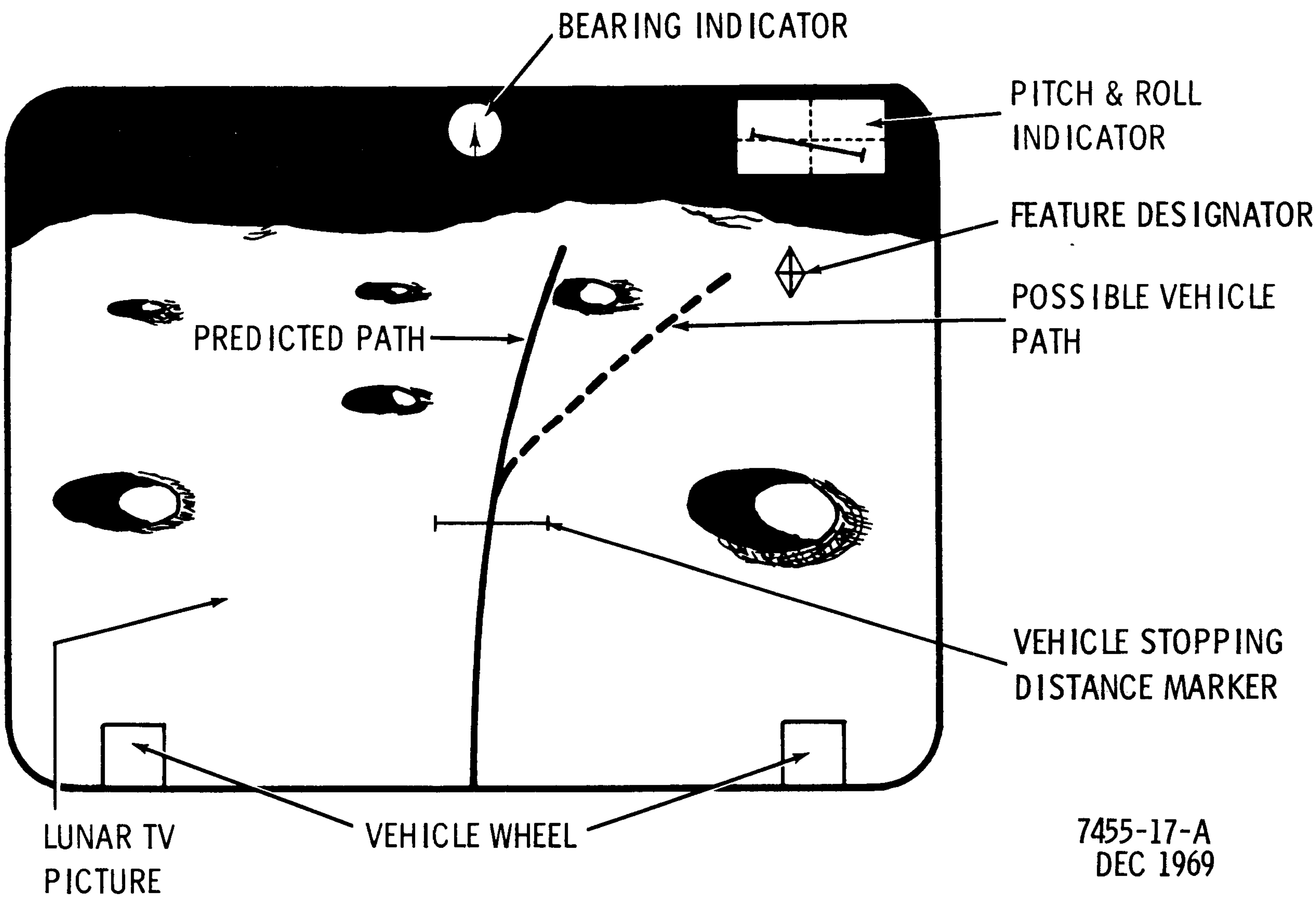

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Figure 4.18-2 Television Display

path. This TV display concept applies to operation of the vehicle in either the step or continuous mode and provides enough information for the operator to operate the vehicle confidently on a safe true course or to recognize hazards for timely avoidance. The dotted line "possible" path is put on the TV screen by manipulation of remote operator hand control for his assessment before the vehicle action is committed. When the possible path is considered proper and safe, a command execute button on the control stick implements the proper vehicle action and the possible path is shown as a predicted path. The roll and pitch indicators aid the remote operator during side slope and during difficult obstacle negotiation. The bearing display minimizes remote operator activity and error in navigation of a minimum course on a given traverse. Additional TV display features include the vehicle front wheels in the TV picture to aid in obstacle negotiation and provide perspective in the picture of objects of known dimensions.

Tables 4.18-1 and 4.18-2 are representative of remote control ground station study of additional display warning requirements for hazard detection and remote control operation procedures to implement obstacle detection and avoidance during remote traverse operations.

Both the DLRV vehicle design and the ground station design have been accomplished with due consideration of the critical component failure modes and alternate or degraded mode possibilities identified by the DLRV failure mode and effect analysis studies. The FMEA data sheets in Section B.5 of Appendix B account for most of the possibilities which may realistically occur. Limited life critical components which may degrade the remote mission by wearout or fatigue failures have been identified as batteries, lubricants, suspension dampers, flexible wheel rings, navigation gyros, and the TV vidicon.

The remote control functions of the DLRV are presented in depth in Vol III, Book 4.

4.19 RTG SAFETY DURING TRANSIT

Because of the stowed DLRV thermal enclosure constraints during the earth-to-moon transit, the RTG temperatures within the generator, including the hot junction temperatures, will rise to a point which could degrade the RTG. By shipping the RTG short circuited during transit, the hot junction temperature will be reduced approximately 100 to 150°F relative to the cold junction temperature and radiator temperature as illustrated in Figure 4.19-1. This provides a temperature margin for thermal integration and precludes degradation of the RTG and adjacent DLRV equipment. The lower hot junction temperature is due to the Peltier cooling effect of the short-circuit current and is discussed in greater detail in Vol III, Book 5.

TABLE 4.18-1

GROUND STATION DISPLAY REQUIREMENTS

7340.76-S

STATUS DISPLAY DLRV -OGE HAZARD WARNING AND VEHICLE SYSTEMS HAZARDOUS COMMANDS					
TM ASSIGNMENT	STATUS INDICATOR/ DISPLAY INDICATION	CONSOLE DISPLAY			
		OPERATOR	MONITOR	NAV	SCIENCE
HH-12	HAZARD RIGHT	PBI-ON	PBI-ON	PBI-ON	PBI-ON
HH-12	HAZARD LEFT	PBI-ON	PBI-ON	PBI-ON	PBI-ON
HH-12	TURN INITIATED	PBI-ON	PBI-ON	PBI-ON	PBI-ON
HH-6	HAZARD RELATIVE BEARING	DIGITAL		DIGITAL	DIGITAL
HH-7	HAZARD RANGE	DIGITAL		DIGITAL	DIGITAL
ND-31/36	VEHICLE STOPPED (ODOMETER ZERO)	PBI-ON	PBI-ON	PBI-ON	
HH-12	LONG RANGE RADAR ON/OFF		PBI		
HH-12	SHORT RANGE RADAR ON/OFF		PBI		
HH-12	LOOSE SOIL RIGHT	PBI-ON			PBI-ON
HH-12	LOOSE SOIL LEFT	PBI-ON			PBI-ON

TABLE 4.18-2

REMOTE OPERATIONS SUMMARY SHEET

DLRV - OBSTACLE ENCOUNTER - CRATER PLUS SLOPES

SEQUENCE	EVENT	COMMAND	MONITOR
1.0	OBSTACLE DETECTION		OPERATOR VIDEO + PATH PREDICTION TDM CURRENTS TDM TEMPS PITCH & ROLL INDICATOR
2.0	GEAR SHIFT FOR UP-SLOPE OPERATION	GEAR SHIFT LOW VEHICLE SPEED/ VALUE	GEAR SHIFT STATUS TDM TRANSMISSION TEMPS TDM MOTOR TEMPS TDM TRANSMISSION PRESS ODOMETERS PITCH & ROLL INDICATOR
3.0	RIMWRIDGE ENCOUNTER		
3.1	DETECTION (BY VEHICLE)		ODOMETER - ZERO IND. HAZARD R/L STATUS LOOSE SOIL STATUS
3.2	TERRAIN ASSESSMENT (VIDEO SURVEY & POSITION UPDATE)	CAMERA AZIMUTH CAMERA ELEVATION TV CONTROLS AS REQUIRED	VIDEO + TERRAIN MAPS VIDEO + TERRAIN MAPS VIDEO
3.3	BACK UP & APPROACH FROM DIFFERENT LOCATION	GEAR SHIFT REVERSE CAMERA AZ 180^0 REL CAMERA EL AS REQD HEADING VALUE SPEED COMMAND/ VALUE	GEAR SHIFT STATUS VIDEO VIDEO ODOMETERS DIR GYRO

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7340-75-S

ETC.

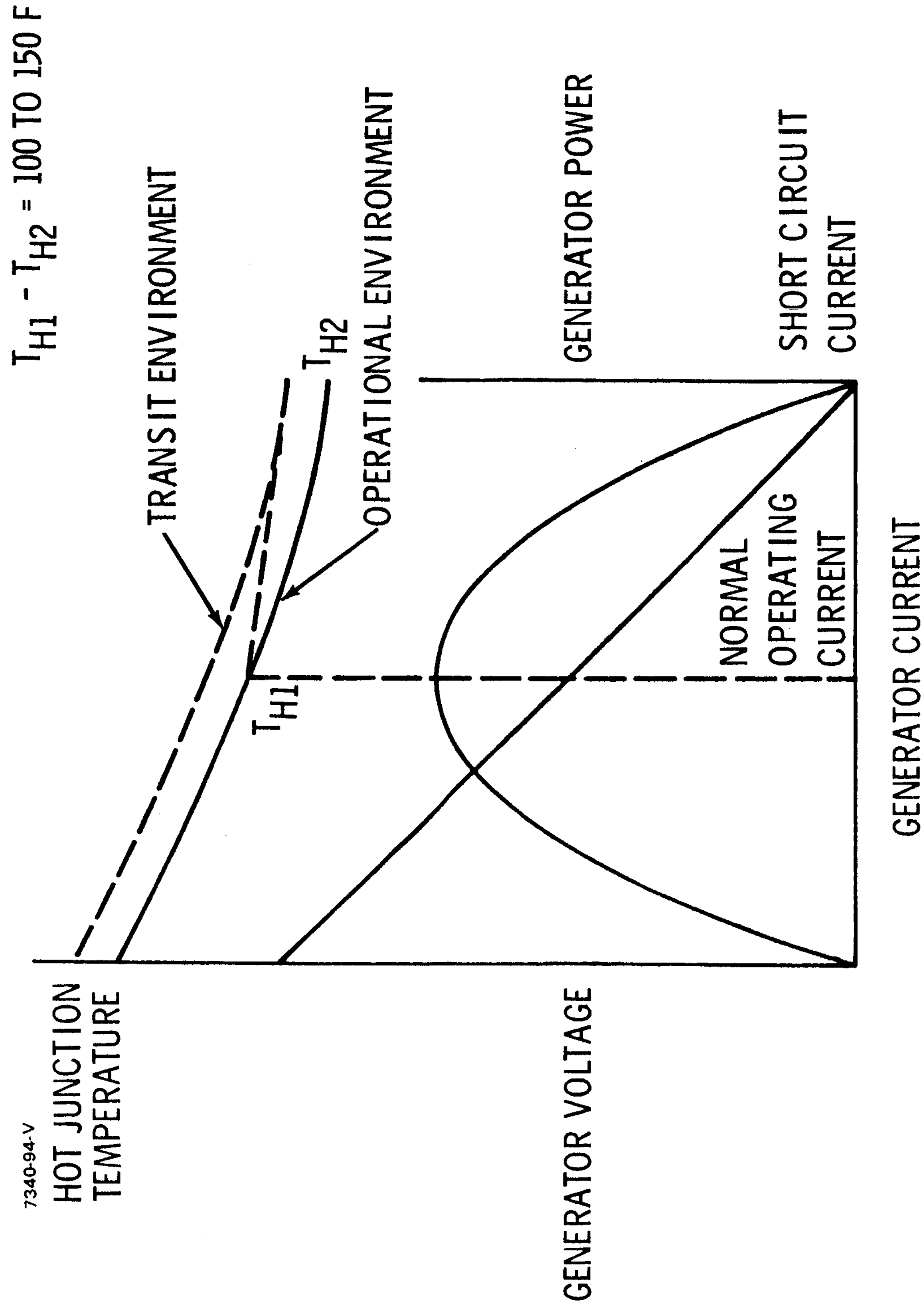

Figure 4.19-1 RTG Electrical Integration During Transit

4.20 DLRV FAILURE MODES AND EFFECTS ANALYSIS

In support of the system safety study requirement to identify and analyze DLRV hazards, a preliminary failure modes and effects analysis of the vehicle subsystems and critical components was performed. The analysis was documented to follow generalized MSFC procedures for FMEA and the detailed results are presented in Appendix B.

Critical component summaries for the manned and remote mission phases are presented in Sections 4.21 and 4.22.

The over-all conclusions from these analyses may be stated as follows:

1. For manned mode operations, the DLRV design for redundancy and alternate mode backup considerations is excellent from the reliability and safety standpoint. No electrical or moving mechanical item category 1 life hazards are apparent in the design.

2. For unmanned (remote) mission operations, the TV, navigation gyro, directional antenna, and wheel ring components of the vehicle merit special development attention for additional redundancy and/or limited life considerations.

3. During the development phase, further FMEA of the DLRV down to the individual parts level and for detailed wiring should be rigorously pursued to ensure that potential failure modes at the component, assembly, and subsystem level are minimized, rather than increased, during the process of final design.

4. During the development phase, the DLRV FMEA for ground station and other OGE should be performed to minimize operational GSE failures which would have a time delay or safety impact on the DLRV lunar surface operations. Further, the ground station and other OGE FMEA should be compared with the detailed vehicle FMEA to assure that all major and minor DLRV failure modes and effects are monitored and factored into the ground station displays, warnings, and controls.

4.21 CRITICAL COMPONENTS, MANNED MISSION

Based on Phase B preliminary FMEA studies of the vehicle subsystems (documented in Appendix B), 16 DLRV component types have been identified as critical items for the manned mode mission.

Table 4.21-1 ranks the 16 critical items in descending order of failure risk and identifies each item by a hazard code.

Category 3 hazards are defined as malfunctions which would have a minor effect on the DLRV performance, but the degraded capability or other backup would allow the basic mission to continue; the six TDMs (taken as a group) and the vertical gyro are the only Category 3 items with a failure risk greater than 0.001. Other Category 3 items with a risk less than 0.001 are not shown in the list.

Hazard Category 2 indicates item malfunctions which would have a serious effect (or safety impact) on the planned mission. There are 14 Category 2 hazard items; each is shown in the table. Only three of the Category 2 items, viz., batteries, navigation computer, and directional gyro, have a greater than 0.001 probability of occurrence.

It is pertinent to note that there are no Category 1 loss of life risks which would be represented as vehicle immobilization failures occurring beyond walk-back range.

4.22 CRITICAL COMPONENTS, REMOTE MISSION

Based on Phase B preliminary FMEA of the vehicle subsystems (documented in Appendix B), 20 component types have been identified as critical items for the unmanned or remote control phase of the DLRV mission.

Table 4.22-1 ranks these 20 critical items in descending order of failure risk and identifies each item by a hazard code.

There are seven Category 3 items which have a failure risk greater than 0.001, but have degraded performance or backup which would allow continuation of the planned mission. The TDMs, TDM controllers, mobility power conditioners, SDMs, SDM controllers, battery ampere-hour sensors, and IR hazard radars are the only Category 3 items which have a mission failure risk significantly greater than 0.001.

There are 13 Category 2 hazards which would seriously degrade the DLRV remote mission. Of these, the six which have a significant probability of occurrence are the vertical gyro, TV camera and electronics, primary batteries, directional gyro, TV position controls, and directional antenna servos. The wheel ring flexible element failure hazards depend on the ultimate fatigue life of the flexible rings, the number of rings per wheel that might fail during an extended mission, and other factors which cannot be evaluated until development tests are performed.

TABLE 4.21-1

CRITICAL COMPONENTS, DLRV MANNED MISSION

FMEA CODE	COMPONENT ITEM NOMENCLATURE	HAZARD CODE	FAILURE RISK
P2	BATTERIES	2	0.0025
N3	NAVIGATION COMPUTER	2	0.0018
M11	TDM ASSEMBLIES	3	0.0017
N1	VERTICAL GYRO	3	0.0014
N2	DIRECTIONAL GYRO	2	0.0011
M5	EMER BRAKE SWITCH	2	NEGL
M8	SHOCK DAMPERS	2	NEGL
N4	ODOMETER SEL CIRCUITS	2	NEGL
P8	BUS RELAYS #1 & #2	2	NEGL
P9	BUSSES #1 & #2	2	NEGL
P16	DEPLOYMENT BATTERY	2	NEGL
C1	DIRECTIONAL ANTENNA	2	NEGL
C2	DIR ANT SERVOS	2	NEGL
C3	DIR ANT DIPLEXER	2	NEGL
C9	DIRECTIONAL COMBINER	2	NEGL
C15	VHF ANTENNA	2	NEGL

7455-199R

HAZARD CODE: 2-DEGRADED MISSION; 3 - MINOR EFFECT

TABLE 4.22-1

CRITICAL COMPONENTS, DLRV REMOTE MISSION

FMEA CODE	COMPONENT ITEM NOMENCLATURE	HAZARD CODE	FAILURE RISK
RC1	TV CAMERA & ELECTRONICS	2	0.620
N1	VERTICAL GYRO	2	0.295
M11	TDM ASSEMBLIES	3	0.278
P2	BATTERIES	2	0.220
N2	DIRECTIONAL GYRO	2	0.217
RC2	TV POSITION CONTROLS	2	0.155
M9	TDM CONTROLLERS	3	0.133
M13	TDM/SDM POWER CONDITIONERS	3	0.091
C2	DIR ANT SERVOS	2	0.062
M12	SDM ASSEMBLIES	3	0.057
M10	SDM CONTROLLERS	3	0.056
P17	BATTERY AH SENSORS	3	0.044
RC3,4	IR HAZARD RADARS	3	0.040
M7	WHEEL RING ELEMENTS	(2)	(?)
P1	RADIOISOTOPE GENERATOR	2	NEGL
P3	RTG SHORT/ON RELAY	2	NEGL
C1	DIR ANT & MW NETWORK	2	NEGL
C3	OMNI ANT & DIPLEXER	2	NEGL
C8	DIR ANT DIPLEXER	2	NEGL
C9	DIR LINK COMBINER	2	NEGL

HAZARD CODE: 2 - DEGRADED MISSION; 3 - MINOR EFFECT

7455-200R

By definition, there are no Category 1 life hazards associated with the unmanned mode remote mission.

4.23 MAJOR ALTERNATE AND DEGRADED MODES

4.23.1 General

Table 4.23-1 depicts several major backup mode characteristics for the DLRV manned mode mission, considering possible failures in the mobility, power, and astrionics subsystems.

The TDM and SDM units are representative of mobility equipment which when functionally divided retains the capability for mission continuation in the event of first failures, and additonal backup capability for extended degraded mode missions and emergency return in the event of two or more failures of the same function.

Similarly, the loss of the RTG in the manned mission has a negligible effect since the primary batteries above are sized to accommodate the manned sorties and supply the RTG/28-v bus loads via redundant series regulators.

The failure of a main bus would not reduce the capability of the DLRV to perform normal sorties; however, the loss of a bus is classified as a degraded mode condition since it is expected that all subsequent operations would be reduced to astronaut walk-back range to prevent a second bus failure from jeopardizing the astronaut's life.

In the astrionics categories, the loss of either the directional or omni communication link is compensated by the use of the other link capabilities. As a minimum, voice and TM are always available as long as one link is functioning. Also, the loss of all vehicle communications would still allow the astronaut to operate within the radio LOS radius of the LM shelter by using his PLSS VHF.

Navigation backup by MCC remote control renders the vehicle mission sensitive only to the loss of vehicle navigation display functions, and the directional gyro. Even the complete loss of DLRV navigation capability will still allow vehicle operations within the visual LOS with LM or other local area landmarks.

Additional major and minor alternate and degraded mode backup characteristics are documented on the FMEA sheets shown in Section B.5 of Appendix B, and in the subsections which follow.

TABLE 4.23-1

MAJOR DLRV ALTERNATE AND DEGRADED OPERATING MODES

7455-201-R

EQUIPMENT ITEMS	MISSION CONTINUATION	DEGRADED MISSION	EMERGENCY RETURN AND WBR OR LOS MISSIONS
MOBILITY	(5) TDM UNITS (3) SDM UNITS (6) DAMPERS	(4) TDM UNITS (2) SDM UNITS (5) DAMPERS	(3) TDM UNITS (1) SDM UNIT (4) DAMPERS
POWER	(1) RTG LOSS - ALL BUSSES	(1) BATTERY (WBR) (1) MAIN BUS (WBR)	(1) BATTERY (1) MAIN BUS
ASTRIONICS	NO OMNI LINK NO VERTICAL GYRO	NO DIRECTIONAL LINK NO NAVIGATION DISPLAY	NO S-BAND COMM NO DIRECTION GYRO

WBR - WALKBACK RADIUS

4.23.2 Mobility Subsystem Backup Modes

The Mobility Subsystem design will prevent the loss of DLRV traction by the following means:

1. Each of the six DLRV wheels is independently powered, controlled, and electrically isolated to prevent propagation of mechanical or electrical malfunctions.

2. In the event of serious mechanical or electrical malfunctions, each wheel's TDM may be mechanically and electrically decoupled by remote control, or manually by the astronaut.

3. Each of the six DLRV wheels is driven by independent power controller channels which may be individually disconnected by automatic circuit breakers, or by the astronaut. Power may also be removed from individual front wheels, center wheel pairs, and rear wheel pairs by means of TDM bus select switching in the remote control mode, or manually by the astronaut switches to the Auxiliary Panel.

4. Individual TDM mechanical and electrical malfunctions are detected by temperature, pressure, and current warnings provided to MCC via telemetry and the TDM warnings on the astronaut display, and by audio warning system on the DLRV.

5. Temperature warnings for each individual TDM motor and transmission are functionally redundant.

6. TDM temperature warnings are functionally redundant with TDM current warnings, and with TDM pressure measurements on telemetry.

7. TDM current and TDM circuit breaker open indications are functionally redundant data available to both the MCC and the astronaut on the vehicle.

8. Remote control pneumatic decoupling of TDMs is backed up by manual decoupling and may be further backed up by the use of pyrotechnic devices.

9. Wheel reliability is enhanced by the use of 20 functionally independent pairs of discrete element rings and oval ring bumpers on each wheel. Individually deformed or failed rings or ring pairs produce no significant immediate effect on performance. Even in the event of extensive

ring damage, wheels are capable of emergency travel on the wheel inner rim structure.

10. DLRV structural failures are avoided by design to limit loads which are four times the static 1-g loads, which are equivalent to two times the full excursion (all four wheels bottoming) loads.

11. Vacuum effects on TDM motors and high-speed transmission are prevented by hermetically sealed hub and nutator gear assemblies.

12. Vacuum effects on TDM low-speed transmission are prevented by the use of dry film lubricants, and backup lubrication may be provided in the form of vacuum stable silicone lubricants.

13. Driving commands from the hand control are effected through dual redundant sensing resolvers and dual electronics from the control stick to the individual TDM power control channels.

14. The total loss of TDM commands at the manual control stick may be offset by MCC remote commands for speed, braking, or reversal of direction control in the event of an emergency.

15. TDM overheating due to lunar dust is prevented by the use of the over-all wheel structures as radiators to minimize dust effects.

16. Design of the DLRV suspension with Coulomb dampers will allow the loss of these components by means of suspension arm travel limit stops and snubbers in the damper, combined with the spring characteristics inherent in the flexible wheel design.

The DLRV Mobility Subsystem design will prevent the loss of DLRV steering functions by the following means:

1. Each of the two front and two rear DLRV wheels is steered by an independent steering drive mechanism (SDM) which is individually powered, controlled, and isolated to prevent propagation of mechcanical or electrical malfunctions.

2. In the event of serious mechanical or electrical malfunctions, each front or rear wheel SDM may be mechanically and electrically decoupled by remote control, or manually by the astronaut.

3. Each of the four SDM units is driven by independent power control channels which may be individually disconnected by: automatic circuit breakers, remote control operation of the circuit breakers, or the astronaut. Power may also be removed from the individual SDMs by bus select switching in the remote control mode, or manually by the astronaut.

4. Individual SDM mechanical and electrical malfunctions are detected by temperature and current warnings provided to MCC via telemetry and to the astronaut by visual observation of the DLRV when in motion.

5. SDM temperature warnings for each SDM motor and transmission are functionally redundant.

6. SDM temperature warnings are functionally redundant with SDM current warnings, and with SDM pressure measurements on telemetry.

7. SDM current and SDM circuit breaker open indicators are functionally redundant measurements available to the astronaut and MCC on telemetry.

8. Remote control solenoid decoupling of individual SDMs is backed up by manual decoupling provisions for the astronaut. Pyrotechnic devices may be provided as an additional backup.

9. Manual steering commands from the mobility hand control are effected through dual redundant electronics from the control stick to the steering power channels.

10. The total loss of steering function at the manual control stick may be offset by MCC remote steering control in an emergency.

11. DLRV wheel designs will allow mechanically decoupled SDMs to free caster on the kingpin pivots after decoupling or to be locked in the fixed straightforward position if desired.

12. Steering electronics may also be operated to provide a scuff steering mode or additional backup flexibility.

The DLRV Mobility Subsystem design will provent the loss of DLRV braking functions by the following means:

1. Each of the six DLRV wheels is provided with individually powered, controlled, and electrically isolated braking functions to prevent propagation of mechanical or electrical braking malfunctions.

2. The parking brake is an automotive-type band brake with internal actuating shoes located in each TDM and energized by small PM motors, screw jacks, and levers which stay locked with the power off.

3. Regenerative braking by the TDM reversal (plugging) and transmission shift clutches provide for braking actions at higher vehicle speeds and operate as a degraded backup for loss of mechanical braking.

4. A push lever may be located on the inboard side of the axle to allow the operator's locking or unlocking the brakes manually if the parking brake motor fails.

5. A grip safety switch on the manual control stick provides emergency braking if the astronaut should become disabled and release the control stick.

6. The loss of individual electrical or mechanical brake functions to any given TDM does not impair the effectiveness of brake functions on the remaining wheels.

7. In the remote control mode, the DLRV radar hazard detection sensors and hazard logic provide for automatic braking of the vehicle in the event the remote control operator does not recognize an unnegotiable hazard on TV.

8. In the remote control mode, the DLRV provides for automatic brake action and automatic retrace (time delayed) if necessary in the event that uplink communication is lost during DLRV travel modes.

4.23.3 Power Subsystem Backup Modes

The vehicle design has been specifically designed to prevent the loss of DLRV power functions by the following means:

1. The dual battery and dual power bus arrangement, combined with commensurate fault isolation and switching flexibility on the DLRV, prevents the disability of any major function in the event of a malfunction within the Power Subsystem or its load services.

2. The possible loss of an RTG during a manned or unmanned mission will reduce the mission to the energy remaining in the two batteries; however, no immediate abort is required in either case.

3. Astrionics, Control/Display, Science, and Heater loads on the RTG will be automatically powered from DLRV batteries through the series regulator in the event of insufficient RTG power or loss of RTG power.

4. Bus-to-battery select relays for mobility loads may be operated either by remote control or by the astronaut to compensate for the effect of either battery or bus malfunctions.

5. Dual charge regulators provide for simultaneous charging of batteries in the normal mode and allow for switching and sequential charging to accommodate the loss of either charger during a mission.

6. Circuit breaker relays which are resettable by remote control are provided to protect the RTG subsystem from charge regulator malfunctions. The batteries and buses for all external subsystem loads are fault isolated by relay reset circuit breakers for Mobility Subsystem loads or by double-diode fusing to protect the power sources from all other subsystem and science loads.

7. Batteries and power system electronics equipment are protected from temperature-induced malfunctions by thermal control subsystem design. Change-of-phase materials and dust covers are employed in DLRV radiator devices to minimize the effects of lunar dust during vehicle travel. Redundant electrical heaters and multilayer insulation techniques provide for reliable protection during lunar day and night temperature extremes.

8. The redundancy of two batteries and two charge regulators allows the unmanned mission to continue with more frequent charge delays but will not impair mobility capability or other vehicle system functions.

4.23.4 Communications Subsystem Backup Modes

1. The DLRV-borne communications are characterized by alternate mode functional redundancy or duplicated standby equipment redundancy throughout the system.

2. The omni and directional antenna links are fully redundant for the uplink and downlink handling of S-band voice and DLRV telemetry.

3. Command receivers and command decoders are fully redundant items which may function on either the omni or directional antenna uplinks.

4. FM/PM power amplifiers, exciters, and modulation processors are fully redundant downlink data handling equipment which may function with either the omni or directional antenna system.

5. The DLRV VHF transmitters and receivers are fully redundant equipment items which may function with the omni or directional antenna S-band antenna links.

6. The possible loss of the directional antenna drive (which would degrade TV and FAX data rates using the omni link) may be offset by vehicle maneuvering to compensate for loss of azimuth pointing, or may be offset by elevation drive decoupling and fixed angle pointing toward earth.

7. The possible loss of the VHF antenna in the manned mode may be offset by the use of an emergency signal key for astronaut transmission of Morse code.

8. The possible loss of the DLRV communications mode select switch on the astronaut control panel may be offset by remote control switching at MCC.

9. The possible loss of power to DLRV communications is prevented by the use of switching regulator functions and power switching which will derive power from either of two batteries in the event of RTG loss or degradation.

4.23.5 Navigation Subsystem Backup Modes

1. The automated navigation designed for remote control is employed in the manned mode as feasible to enhance astronaut safety by reducing astronaut activity and to preclude the occurrence of an inadvertent astronaut error.

2. The manned mode vehicle-borne navigation is designed with full capability to allow for any loss of communications with earth during sortie operations.

3. All DLRV navigation computations performed by the DLRV are duplicated by earth remote control navigation.

4. All DLRV navigation displays and controls provided to the astronaut are backed up by remote commands and telemetry.

5. The loss of the DLRV directional gyro is the only effectively non-redundant function of the DLRV navigation equipment. Landmark navigation and sun angle observation techniques would be used in the event of directional gyro failure during lunar traverse operations. TV/FAX landmark recognition, backup navigation techniques would be employed for remote control mode operations in the event of directional gyro failures.

6. The loss of TV for remote navigation may be compensated for by the use of the facsimile camera in the step mode aided by IR hazard sensors for safety.

7. The loss of the vertical gyro may be compensated for by earth-based navigation updates for accuracy whenever landmarks are available.

4.23.6 Astronaut Control and Display Backup Modes

Single point and critical crew station control, display, and warning failures have been prevented by the following means:

1. The astronaut operator control functions on the DLRV are functionally redundant with remote control commands to provide for earth backup of speed, steering, braking, reverse driving, gear switching, power management, navigation, and communication control functions.

2. The DLRV hand control stick employs two sets of linear differential transformer assemblies to provide standby redundant speed, steering, and brake control circuits. Additionally, each of these functions is controllable by remote commands in the event of an emergency.

3. The DLRV operator's console incorporates navigation display and communication mode select switches whose functions may be commanded by remote control. Navigation data being computed on earth may be furnished the astronaut via the communication uplink. Communication equipment modes may be relay-selected by the remote operator commands as a backup to astronaut C&D switching.

4. The DLRV operator's console incorporates an emergency signal key which may be used to send code messages in the event of DLRV-VHF or astronaut PLSS-VHF equipment losses beyond radio LOS with the LM.

5. The DLRV operator's console Bus Select and DLRV auxiliary panel TDM/SDM Bus Select switches may be changed or reset by remote control in the event of switch malfunctions.

6. The TDM and SDM electrical power and mechanical decoupling switches on the DLRV auxiliary panel may be actuated by remote control in the event of any switch malfunction.

7. The DLRV Bearing Display Selector Switch and the DLRV Navigation Data Select Switch provide on-board switching flexibility to compensate for the loss of either switch function for on-board heading data.

8. All DLRV display and warning data provided on the astronaut's display console and the vehicle audio warning system are telemetered to earth control for possible radio relay back to the astronaut in the event of any DLRV display malfunction, or in the event that visual displays are unnoticed during driving operations.

9. The on-board DLRV audio warning system provides a real-time backup to caution and warning lights on this DLRV operator's console.

10. The loss of any individual TDM, stability, battery, and gyro warning lamps on the DLRV operator's console is unlikely since dual-lamp elements are used in these status lights.

11. The loss of the DLRV bearing indicator may be compensated for by the on-board use of the NAV data display.

12. The loss of the DLRV NAV data display may be compensated for by the use of the Bearing Indicator for heading to site or heading to LM and distance traveled, or position data may be obtained from earth remote control.

4.23.7 Remote Control and Hazard Warning Backup Modes

1. The possible loss of DLRV TV camera or TV pointing controls may be compensated for by the use of the facsimile camera for remote control operator use in the stop mode.

2. The possible loss of the directional antenna drive for TV may be compensated for by the use of omni downlink transmission at a reduced data rate in the step mode or by the use of vehicle pointing maneuvers in the step mode.

3. The possible loss of long- or short-range radar hazard warnings may be compensated for by the use of medium-range radar for near hazard and by the more extensive use of TV and facsimile camera for hazard observation at medium ranges.

4. The possible loss of power to hazard warning devices is prevented by the DLRV power switching flexibility which will allow the RTG or either of the two batteries to provide necessary power.

5. The possible loss of command to the Hazard Detection and Warning Subsystem is prevented by fully redundant uplink and downlink communication services, receivers, and command decoders on the DLRV.

6. The possible loss of specific mobility, power, command, communication, and navigation subsystem functions are prevented by the means described in the preceding subsections.

7. The vehicle-borne science for remote control deployment could malfunction in the release mode and encumber the subsequent DLRV operation. Backup release devices installed at the tiedown interface with the chassis may be actuated by MCC command to prevent such hangups.

SECTION 5

OPERATING SAFETY SUMMARY

5.1 MISSION SEQUENCE HAZARD SUMMARY

Table 5.1-1 presents a preliminary outline of mission hazards and hazard reduction methods or approaches which have been considered during the Phase B study. The mission sequence considers the major phases, events, and possible hazards beginning with prelaunch activity at KSC, and the sequence is carried through the conversion of the DLRV vehicle and its science for remote control unmanned operation. The operation of MCC ground station equipment, its detailed functions, possible errors, etc., are not included; these operations should be covered by detailed operating sequence analyses performed in development phase safety analyses, including considerations which are discussed in Section 4.18.

The operating safety summary has been presented as briefly as possible using cryptic phrases where feasible to identify the hazard or reduction method ideas for quick visibility. More extensive discussions of the nature of the particular hazard and its treatment are included in other sections of this report.

5.2 SUMMARY OF RECOMMENDATIONS

This section reviews: (1) safety hazards and/or areas of hazard reduction which are considered most important for follow-on development phase attention, (2) safety-oriented suggestions for astronaut and vehicle remote control operator training, and (3) safety requirements and guidelines which should be included or further developed for inclusion in DLRV System and equipment specifications.

5.2.1 Areas for Further Safety Investigation

Safety analyses by design, crew engineering, system engineering, and other DLRV project groups during the development phase should emphasize the following areas of investigation for design, test, or other means of hazard reduction:

1. Vehicle static and dynamic stability

2. DLRV caution and warning redlines

TABLE 5.1-1

DLRV MISSION SEQUENCE HAZARD SUMMARY SHEET

DLRV MISSION SEQUENCE HAZARD SUMMARY SHEET

Phase/Event	Hazard Description	Hazard Reduction/Control Approach
Prelaunch Inspection and Handling	. Damage to 1/6-g vehicle structure . Degradation of thermal coatings . Loss of TDM/SDM pressurization . Excessive connector cycling	Fixtures, covers, inspections, test procedures, indoctrination and training must be developed to minimize risk of KSC processing hazards
Prelaunch Integration and Test Activity	. Battery forming and charging . Thermal hazard of RTG heat simulator checks . Mating and unmating of fore and aft connections	. Use of vendor-validated precautions . Protect from accidental contact with personnel on flammable material . Radiographic inspection after last disconnect before flight
Installation on LM	. Mechanical damage to LM structure or tiedown points	. Installation guide fixtures and rehearsal-proved precaution required
	. Damage to LM thermal insulation	. Same as above plus post-installation inspections
	. Damage to DLRV structure	. Same as above
	. Damage to DLRV thermal coatings or insulation	. Same as above
	. Damage to TDM or SDM dynamic seals	. Pressure measuring instrumentation and post-installation checkout
	. Damage to DLRV unloading booms, cables, winches, or thermal blankets	. Pre-DLRV installation checkout with 1/6-g simulator plus post-DLRV installation inspections
	. Damage to vehicle-borne science equipment	. Post-installation inspections
Prelaunch Checkout and Standby	. Battery installation injury hazards to pad crew	. Simulate installation and backout procedures with mockup to validate safety precautions
	. RTG installation injury hazards to pad crew	. Same as above
	. RTG fuel thermal effects on launch pad crew	. Simulate installation and backout procedures, safety precautions and protection devices for

FOLDOUT FRAME

	P/CCDT	
	. RTG fuel radiation effect on launc[h] pad crew	. Same as above. Fuel to be loaded as late as practical in countdown to minimize personnel exposure
	. Battery malfunction on pad before launch	. Temperature measurements plus rehearsals as noted above
	. RTG thermal surfaces on pad before launch present potential explosion hazard	. Auxiliary cooling system to be provided to maintain RTG temperature below critical level
Launch, Transit, and Lunar Landing	. Loss of DLRV vehicle and equipment tiedown integrity	. Design to meet specific safety factors; proof test system model and critical parts
	. Short failure of DLRV battery, overheating, or expulsion of electrolyte	. Vendor design analyses, and development tests specified to prove hazards are eliminated
	. Overheating of RTG due to open-circuit loading	. Redundant shorting connections for RTG to be provided
	. DLRV damage from LM RCS plume	. LM thermal test data used to define adequate insulation
	. RTG thermal and ionizing radiation input to LM	. RTGs on DLRV are installed facing outboard from chassis to minimize effects
Deployment	. Backlash from deployment winches	. Incorporate irreversible gearing in winch design
	. Unable to maintain stability on ladder while performing deployment tasks	. Design to assure stability while performing deployment tasks; verify during crew integration tests
	. Structural failure in LM ladder	. LM/DLRV interface analysis to verify capability of LM structure to accept DLRV loads
		. Visual inspection by crew prior to initiation of deployment tasks
	. DLRV falls on astronaut on ladder	. Design to preclude hazard during deployment sequence
	. DLRV falls on astronaut on lunar surface	. Verify astronaut is clear of area before initiating deployment sequence
	. Adverse lighting may not permit observation of DLRV as it deploys	. Design to permit task to be accomplished without visual reference; verify during crew integration tests
	. Forces required to operate winches, lanyards, and release pins may exceed astronaut capabilities	. Design to preclude; verify during crew integration tests

FOLDOUT FRAME 2

FOLDOUT FRAME

TABLE 5.1-1 (CONT.)

Phase/Event	Hazard Description	Hazard Reduction/Control Approach
Assembly and Checkout	. Communications mast may not lock into erect position and may subsequently fall on astronaut	. Design to permit positive verification of mast lock engagement; . Astronaut to verify
	. Following erectable assemblies could create EMU pinch or puncture hazards: Console Assembly Seat Assembly Communications Mast Staff Tracker Step Restraint Arm	. Design to preclude; verify during crew integration tests
	. Lack of lunar driving experience may result in collision with LM or rear section when backing up forward section for hookup	. Ground training program . Use extreme care while maneuvering in the immediate vicinity of the LM
	. Heat radiated from RTG may affect EMU integrity while performing checkout tasks at auxiliary panel	. Analysis to determine criticality of RTG heat radiation on EMU
	. RTG neutron emission level is significant to astronaut career cumulative allowable exposure	. Crew Task timelines to minimize tasks in immediate presence of RTG
	. Making or breaking of "HOT" electrical connections prohibited on lunar surface	. Provide "SAFETY SWITCHES" on rear section to de-energize interconnect cables during hookup
Lunar Mobility Operations	. Dust degradation of thermal control surfaces	. Manned mode - brush off surfaces as required . Unmanned mode - activate dust removal devices as required . Provide debris guards to minimize dust impingement

	. Glare from thermal control surfaces interfere with astronaut vision	. Potential hazard only during backup maneuvers; design to minimize potential
	. Dynamic instability of vehicle could result in turnover if operated at excessive speed on rough surface	. Design to maximize vehicle stability . Provide positive warning of impending unstable condition . Mechanize mobility controller to vary maximum speed as a function of surface condition . Astronaut training to recognize and avoid hazardous conditions
	. Static instability of vehicle could result in turnover in an attempt to negotiate excessively steep obstacles	. Design to maximize vehicle stability . Provide positive warning of impending vehicle instability . Astronaut training to recognize and avoid or negotiate hazardous conditions
	. Impact crash could result from contact with unnegotiable obstacles; i.e., boulders, crevasses, sheer projections on lunar surface	. Design to provide unimpeded forward visibility . Design to provide positive redundant braking and steering capability within the hazard detection distance at maximum operating speed
Convert to Remote Configuration FOLDOUT FRAME 2	. Hazards related to initial assembly and checkout tasks generally apply	
	. Neutron emission from RGMs is significant to astronaut career cumulative allowable exposure	. Crew task timelines to minimize tasks in immediate presence of RGMs
	. Making or breaking of "HOT" electrical connections prohibited on lunar surface	. Provide "SAFETY SWITCHES" to isolate RGM and DLRV Power while making RGM connections
	. Manipulation of science packages may overtax astronauts or jeopardize EMU integrity	. Design to preclude; verify during crew integration tests
	. Ascent stage launch may cause vehicle damage	. Vehicle to be driven remotely to a safe distance prior to launch of ascent stage

3. Latest Apollo mission-determined knowledge and criteria on the effects of:

    a. Astronaut visibility under lunar surface lighting conditions

    b. Lunar surface soil characteristics

    c. Radio and visual LOS on the moon

    d. Lunar surface dust characteristics

    e. Lunar gravity effects on man and machine dynamics

4. LM loading of DLRV on TDU designed for operation at 1/6 g

5. Injury hazards to launch pad crew in loading DLRV batteries or RTG and during contingency backout operations

6. Recovery of a disabled astronaut driver or other crewman

7. Extrication of entrapped DLRV: conditions; design aids

8. Lunar subsurface voids detection; vehicle recovery

9. Safe astronaut walk-back radius on moon

10. RTG thermal radiation radius and exposure time effect data for 250°F limits on EMU visor

11. Analysis of Apollo crew radiation exposure histories

12. Analysis of dust deflection and dust removal techniques

13. EMU deterioration from ingress/egress and seated driving operations, EMU wear points, dust abrasion, etc.

14. Visibility of displays and warnings under all lunar lighting conditions

15. Crash safety analyses, manned and unmanned modes

16. Analysis of astronaut DLRV operator errors

17. Additional DLRV failure modes and effects study

18. Additional ground station failure modes and effects studies

19. Added safety analysis for astronaut and remote control operator training (Section 5.2.2)

20. Added safety analysis for safety requirements input to all level of DLRV, ground station, and interface specifications (Section 5.2.3)

21. Additional redundancy studies (Appendix B, Section B.1).

5.2.2 Astronaut and Remote Operator Training

Crew Engineering-formulated preliminary plans for astronaut training are described in the Crew Station Development Plan (Vol VII, Book 1). Safety considerations for both normal and contingency operations are included as a basic element in the over-all training concept.

Bendix planning initiates crew and vehicle operation training with the 1-g Mobility Test Article No. 1, which will encompass mission task simulations for the full manned mission, including all vehicle and equipment capable of being stowed or deployed in DLRV operations.

Specific training activity requirements and the model and facility association referenced below reflect safety emphasis in the preliminary astronaut training plans:

Training Requirements	Model/Facility
DLRV Initial Removal	A, E, F
DLRV Deployment	A, E, F
DLRV Checkout	A, B, E, F
DLRV Science Stowage	A, B, C, E, F
DLRV Science Removal	A, B, C, F
DLRV Ingress, Driver Station	A, C, E, F
DLRV Ingress, Contingency Station	A, C, E, F

Training Requirements	Model/Facility
DLRV Egress, Contingency Station	A, C, E, F
DLRV Egress, Driver Station	A, B, C, E, F
DLRV Driving Tasks	A, B, D, F
DLRV Navigation Tasks	A, B, D, F
DLRV Contingency Tasks	A, B, D, F
DLRV Site Survey Tasks	A, B
DLRV Instrument Activation	A, B
DLRV Sample Collection	A, B
DLRV Conversion to Unmanned Mode	A, B, F
DLRV Conversion to Manned Mode (After Rendezvous)	A, B, F
DLRV Contingency Operations	A, B, C, E

A - 1-g Trainer, MSC

B - 1-g Trainer, USGS

C - 1/6-g Trainer, KC-135

D - 1/6-g, MSC Visual Simulator

E - 1/6-g, Underwater Facility

F - 1-g Mockups, Lunar Lighting Facility

Preliminary design of the DLRV Ground Control Station has been based on detailed consideration of: all mission critical operating modes; failure modes; telemetry monitoring of all DLRV critical functions, warnings, and failure modes; hazard detection and avoidance; alternate mode navigation techniques; operating the vehicle with RF propagation delay variations from 2.6 to 22 seconds; and the remote control driving recovery of an incapacitated astronaut. Extensive training for normal operating conditions will be necessary for all normal mission variables. However, contingency operating modes will compound operational variations to a degree which will require computer analysis to select and present proper and safe routines for specific individual and combinations of emergency modes.

Trade-off studies of operator routines vs. automated or semiautomated mission sequence routines for emergencies are required during the development phase before deciding final man vs. machine operating techniques and control console equipment details. Training considerations should be factored into these trade-off analyses.

5.2.3 Program and Equipment Specifications

Safety requirements and constraints were defined for inclusion in the DLRV System Specification and Requirements Document (Vol VIII of this report). Safety requirements were detailed under the categories of: (1) stability, (2) brakes, (3) astronaut accomodation, (4) crew and/or vehicle recovery, (5) launch site safety, (6) tiedown and deployment, (7) safety factors, and (8) batteries.

An excerpt of these safety specifications is provided in Appendix A.

The "System Specification and Requirements Document" should be updated during the development phase with additional safety requirements and criteria based on further design analysis and development testing to: (1) establish caution and warning conditions or redlines, and (2) delineate subsequently discovered hazards and the specific means which should be applied for hazard prevention or control to acceptable levels.

Safety requirements should also be derived from the System Requirements Document during the development phase and embodied into subsidiary DLRV system equipment specifications, viz, the individual specifications for the: (1) DLRV vehicle, (2) vehicle subsystems, (3) DLRV TDU Subsystem, (4) DLRV GSE, (5) OGE, (6) DLRV/LM Interface Control Document, (7) DLRV/Astronaut Interface Control Document, (8) DLRV Science Interface Control Document, and (9) critical components.

The project, system, equipment, and interface specifications cited above should be maintained to embody the latest current lunar surface knowledge available from Apollo missions, e.g., soil characteristics, lunar lighting conditions, lunar dust, radio and visual LOS criteria, and lunar gravity effects on man/machine dynamics.

APPENDIX A

SAFETY REQUIREMENTS EXCERPT FROM PROPOSED DLRV SYSTEMS SPECIFICATION*

3.1.2.7 Safety.

3.1.2.7.1 Stability. - The DLRV shall be designed to prevent overturning under the maximum conditions established in Paragraph 3.1.1.3. Visual/aural means shall be provided to warn the driver when the DLRV is operating under conditions approaching the stability limits established above. An adequate margin shall be established, by means of analysis and/or dynamic testing, to assure adequate response time so that, assuming reasonable driver reaction, it is impossible to turn the vehicle over under any expected lunar traverse conditions.

3.1.2.7.2 Brakes.

(a) Redundant braking system: A redundant braking system shall be provided to permit the astronaut driver to execute a complete stop from the maximum speed established in Paragraph 3.1.1.1 within a distance less than that from which any obstacle defined as unnegotiable in Paragraph 3.1.1.3 can be perceived, with driver reaction time taken into account. In the unmanned mode the DLRV redundant braking system integrated with hazard logic shall permit a complete stop from the maximum speed defined in Paragraph 3.1.1.2 within a distance less than the forward section wheel base upon receipt of a stop signal from the on-board Hazard Detection and Avoidance Subsystem.

(b) Emergency/parking brake: An emergency/parking brake shall be provided to stop and maintain the DLRV on slopes identified in Paragraph 3.1.1.3. This brake shall require no power to statically maintain the DLRV in the braked/parked condition.

(c) Safety switch: A safety switch shall be provided which will render the vehicle immobile either in the absence or incapacitation of the astronaut driver.

* Refer to Volume VIII of this report.

3.1.2.7.3 Astronaut accommodation. - The number and complexity of astronaut tasks, the amount of time required for the performance of these tasks, and the amount of energy expended by the astronaut for DLRV operations shall be minimized through hardware design. The following constraints shall be considered in design:

(a) There shall be no hot electrical connections made during EVA.

(b) The seat support and restraints shall incorporate provisions for rapid emergency egress from the DLRV.

(c) Communications between both crewmen and MCC will be required at all times.

(d) Positive driver control shall be required to maintain vehicle in motion.

(e) The driver's vision shall not be impaired by glare from reflecting surfaces of the DLRV.

(f) The driver shall be provided with adequate visibility for driving in reverse.

(g) Maximum temperatures of all surfaces with which the astronauts may come in contact, either in the performance of their tasks or inadvertently, shall be less than the maximum prescribed to maintain EMU integrity.

(h) Emergency controls shall be so positioned and identified that they may be operated without visual reference.

(i) Warning placards, lights, and vital data displays shall be visible under all lunar lighting conditions.

(j) All sharp edges, corners, protrusions, etc., which could damage or entrap the EMU, either at the crew station or in performance of tasks on or about other parts of the DLRV, shall be eliminated.

3.1.2.7.4 Crew and/or vehicle Recovery.

(a) Sufficient power reserve shall be maintained during all manned mode sorties to permit emergency return of the DLRV to LM on one battery.

(b) Sufficient on-board navigational capability shall be provided during all manned mode sorties to permit emergency return of the DLRV to within visual LOS of the LM in the event of loss of primary navigational functions, or loss of power to DLRV navigation.

(c) Handholds or other devices shall be provided to facilitate extrication of an entrapped DLRV by the astronaut.

(d) Capability shall be provided to permit a second astronaut to drive the DLRV in the event the first astronaut becomes incapacitated in the driver's seat.

(e) Capability shall be provided for remote driving of the DLRV from MCC in the event that the driver becomes incapacitated on a solo traverse.

(f) Restraints shall be provided, as required, to secure an incapacitated astronaut.

3.1.2.7.5 <u>Launch site safety.</u> - The DLRV shall be so designed and oriented in the stowed configuration to facilitate installation and/or backout procedures for the flight batteries and the RTG fuel capsule late in the countdown. Representative RTG and battery temperatures shall be read out continuously up to the time of launch.

3.1.2.7.6 <u>Tiedown and Deployment.</u> - The tiedown and unloading equipment shall be designed to stabilize the DLRV forward and aft sections during unloading in a manner to prevent possible damage or injury to the DLRV, LM, and the astronaut.

3.1.2.7.7 <u>Electroexplosive Devices (EED).</u> - The use of EEDs shall be minimized. No Category "A" or "B" ordnance devices shall be utilized in the design of the astronaut interface. Where EEDs are utilized in the design of the DLRV, they shall comply with the following requirements:

(a) They shall be Single Bridgewire Apollo Standard Initiators (SBASI).

(b) They shall be incorporated into the system in accordance with the latest requirements for range safety.

(c) They shall be protected by at least two nonstorable commands from ground.

(d) Firing circuits shall be isolated in the DLRV System and shall contain protection from induction, stray voltage, and interference from other circuits in the system.

3.1.2.7.8 Safety factors. - Structural design shall be based on a safety factor of 1.5 for the maximum expected loads.

3.1.2.7.9 Batteries. - DLRV batteries shall not create fire, explosion, liquid spillage, or outgassing hazards under any condition of storage or operation during the useful life of the DLRV.

APPENDIX B

DLRV FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

B.1 INTRODUCTION

Although not explicitly required by the Statement of Work or the Phase B study plan (Document of Understanding), a formal Failure Mode, Effect, and Criticality Analysis (FMEA) study was performed: (1) to support the System Safety Analysis, Task K, (2) to identify areas where design may employ redundancy for the most advantageous effect on crew safety and/or mission success, and (3) to identify design and component areas which should be given greatest attention during later design and development phases.

The DLRV Statement of Work required that "the LRV shall be specifically designed to prevent single point failures from aborting the missions."

From the outset of the Bendix DLRV study, beginning in April 1969, configuration and subsystem trade-off studies were aimed at achieving this objective. Based on the above rationale, the DLRV System has evolved with the redundancy or alternate mode flexibility to prevent the following potential catastrophic failures: (1) loss of traction, (2) loss of steering, (3) loss of brakes, (4) loss of power, (5) loss of operator controls, (6) loss of displays and warnings, (7) loss of navigation, (8) loss of communication, and (9) loss of remote control.

To accomplish this, the initial DLRV configuration candidates were conceived as functions to be divided or arranged for the greatest possible alternate mode performance in the event of critical component failures. Thus, the effect of redundancy was generally achieved without the weight penalties of fully redundant equipment.

In considering the 750-lbm total weight constraint for the DLRV including its scientific payload and lunar support equipment, the redundancy of vehicle was considered of primary importance, and redundancy of tiedown/unloading of secondary importance.

Since the DLRV vehicle itself, when operating in the manned mode, is the most important equipment in the system from the safety standpoint, greatest attention was placed on the manned DLRV failure modes which could jeopardize the astronauts' safe return.

The primary objective in the remote control mode was to ensure that the DLRV was designed to minimize the effect of malfunctions that would abort or severely degrade the 1000-km mission.

B.2 SUMMARY

This appendix presents the results of the DLRV FMEA performed in support of the Task K DLRV System Safety Study and as an aid in the achievement of a vehicle design characterized by the absence of single point failure modes.

Section B.3 describes how the FMECA was performed, considering MSFC procedure guidelines, and presents significant critical component evaluation data derived from the analysis.

Section B.4 provides recommendations for subsequent development phase design and analyses, suggestions for development phase test and controls, and other program considerations indicated by the findings of the Phase B FMECA study.

Section B.5 incorporates the detailed FMEA analysis data sheets prepared as the foundation of the FMECA study.

B.3 DETAILED FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS

B.3.1 Procedure Outline, FMECA Study

Employing MSFC Drawing No. 10M30111, Rev A, "Procedures for Performing System Design Analysis" as a general guide, the DLRV vehicle subsystems and major components were studied during the Phase B preliminary design, and the results were documented. The FMECA study was organized and implemented as follows:

1. The DLRV subsystems and components were identified by nomenclature, functions, and components using the functional block diagrams presented in the Monthly Program Review reports and final report of the study.

2. Subsystem, equipment, and components were defined on FMEA analysis sheet forms to reflect functional descriptions and assumed failure modes for each component item as shown in Section B. 5 for: (a) manned mission, and (b) remote mission operations.

3. The mission effect and functional effects of each assumed failure mode were analyzed and documented on the FMEA analysis sheets together with explanations of backup, alternate mode, or other mission operation compensations which may apply.

4. For each subsystem a component criticality determination was performed using hazard category definitions and failure probability classification data explained in Section B. 3. 4.

5. The mission effect and failure risk critical items for the DLRV were reviewed for ranking considerations of the manned mode mission as shown in Section B. 3. 5 and the remote mission as shown in Section B. 3. 6.

6. Recommendations derived from the FMECA analyses are summarized in Section B. 4.

7. FMEA analysis sheets are provided in Section B. 5.

B. 3. 2 Mission Assumptions

Basic assumptions used for the manned and unmanned mission modes were derived from the Phase B study Statement of Work and the results of the Bendix study. These assumptions are as follows.

B. 3. 2. 1 Manned Mission Assumptions

Staytime: 78 hr on the lunar surface

Sorties: A maximum of four DLRV operational sorties preceded by a deployment and checkout EVA.

Mobility Range: Maximum of 120 km or 30 km per sortie at a maximum speed of 15 km/hr.

Mobility Operating Time: A minimum of eight travel hours for 120 km, or 2 hr for each 30-km sortie. Checkout driving time is included in the time considered for the first sortie.

Mobility Operational Area: Unrestricted up to 10 km from the LM, except in the event that equipment malfunctions reduce operating areas to walkback radius range for safety.

Power System Operating Time: A nominal 50 hr considered from time of subsystem turn-on at EVA No. 1 checkout until the completion of sortie No. 4.

Communications Subsystem Operating Time: A nominal 50 hr for omni link associated functions including telemetry during manned operations and standby; a nominal 15 hr of operating time directional link equipment during the four 220-minute DLRV sorties.

Navigation Subsystem Operating Time: A nominal 15 hr for vehicle navigation equipment during the four 220-minute sorties.

B.3.2.2 Unmanned (Remote) Mission Assumptions

Total Time: Approximately 1.1 year of lunar surface operation including day operations and night survival following manned deployment, checkout, manned mode mission, and conversion of science for unmanned mission operations.

Mobility Range: 1000-km map distance plus approximately 20% added travel for detours and science activity en route.

Mobility Operating Time: Approximately 1300 hr allowing for 0.5-km/hr speeds on rough surfaces and up to 2 km/hr on smooth surfaces.

Power System Operating Time: Approximately 10,000 hr for RTG power source and associated electronics, heaters, etc., during lunar day and night standby. Approximately 3100 operating hours for 1300 hr of mobility operation and 1800 hr of science activity. Approximately 1300 hr of power recharge time between active mobility and science periods.

Communications Subsystem Operating Time: Approximately 10,000 hr for omni link and receiver equipment. Approximately 3100 hr for all other equipment and telemetry during 1300 hr of mobility and 1800 hr of science operations.

Navigation Subsystem Operating Time: Approximately 3100 hr of operating time for all vehicle equipment during 1300 hr of mobility and 1800 hr of science operations.

TV and Hazard Detection Operating Time: Approximately 3100 hr of operation to correspond with vehicle mobility operations and science for TV; 1300 hr of operation for hazard detection during vehicle mobility operations.

B. 3. 3 Subsystem Failure Modes and Effects Analysis

Subsystem FMEA sheets were prepared for the following DLRV subsystems:

1. Manned Mode Failure Mode Analysis

   Mobility Subsystem, 15 items

   Power Subsystem, 17 items

   Communications Subsystem, 21 items

   Navigation Subsystem, 11 items

   Remote Control Subsystem, 2 items

   Controls and Displays, 5 item groups

2. Remote Control Mode Failure Analysis

   Mobility Subsystem, 11 items

   Power Subsystem, 13 items

   Communications Subsystem, 15 items

   Navigation Subsystem, 6 items

   Remote Control Subsystem, 4 items.

The individual component items are conveniently summarized by subsystem in Section B. 3. 4. The reader is referred to Section B. 5 for the detailed loss, effect, and operational backup statements.

DLRV unloading and deployment subsystem components and vehicle structure items have not been included in the Phase B analysis based on NASA FMEA guidelines which generally exclude structure and mechanical parts. Development phase FMECA should include those items, however, and include design stress analysis and development proof testing backup data to assure design safety margins.

Items such as detailed wiring and connectors are not included in the Phase B analysis because of: (1) the design intent to provide redundancy to the extent feasible, and (2) NASA procedures delineated in MSFC Document R-ASTR-S-67-35 should be applied during the development phase design to eliminate or minimize critical failure modes.

The Phase B FMECA does not extend below the level of the critical assembly, i.e., TDM or power conditioning module, to identify critical parts. However, items such as bearings, motor windings, etc., are considered to be accounted for in the failure mode or loss statements for the assemblies or modules identified in the Phase B study. It is believed the over-all study results are a realistic summary of all subsystem critical functional failure modes and effects important to identifying areas of development phase attention.

B.3.4 Component Criticality Determination

Tables B.3-1 through B.3-6 document probability of failure and failure effect classifications for all major or significant DLRV vehicle components reviewed in the Phase B study. The FMEA identification code and component item descriptions match the FMEA code and nomenclature provided in the Section B.5 analysis sheets for easy cross reference.

The failure effect category classification numbers represent mission hazard codes which are defined as follows:

Category 1 - Immediate Risk of Life, e.g., vehicle is immobilized beyond astronaut walk-back range.

Category 2 - Degraded Mission, e.g., planned mission must be reduced in scope to allow for degraded performance, or emergency return be initiated for manned mode safety.

Category 3 - Minor Effect in Mission, e.g., mission may continue with minor changes, if any, in the baseline mission plan.

TABLE B. 3-1

MOBILITY COMPONENT CRITICALITY DETERMINATION DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
M1	Aft Unit Connections	Red't	50	Negl.	3	10,000	Negl.	3
M2	Hand Control (Resolvers)	Red't	8	Negl.	3	NA	NA	NA
M3	FWD/REV Switch	Negl.	Negl.	Negl.	3	NA	NA	NA
M4	HI/LOW Gear Switch	Negl.	Negl.	Negl.	3	NA	NA	NA
M5	EMER/PARK Switch	Negl.	Negl.	Negl.	2	NA	NA	NA
M6	TDM TEMP/CURR Lamp	Negl.	Negl.	Negl.	3	NA	NA	NA
M7	Wheel Assy (Rings)	(?)	1×10^4 Rev.	Negl.	3	4×10^5 Rev.	(?)	(?)
M8	Shock Dampers (6)	(?)	1×10^3 cyc	Negl.	2	1×10^4 cyc	(?)	3
M9	TDM Controllers (6)	102	8	0.0008	3	1,300	0.133	3
M10	SDM Controllers (4)	43	8	0.0003	3	1,300	0.056	3
M11	TDM Assemblies (6)	214	8	0.0017	3	1,300	0.278	3
M12	SDM Assemblies (4)	44	8	0.0003	3	1,300	0.057	3
M13	Power Conditioners (6)	70	8	0.0006	3	1,300	0.091	3
M14	TDM/SDM CCB Relays (10)	Negl.	Negl.	Negl.	3	Negl.	Negl.	3
M15	DYN Stability IND	Negl.	8	Negl.	3	NA	NA	NA
M16	TDM Mode Logic	Red't	NA	NA	NA	Negl.	Negl.	3
M17	SDM Mode Logic	Red't	NA	NA	NA	Negl.	Negl.	3

Notes: Red't - Redundant; Negl. - Negligible; NA - Not Applicable; (?) - Unknown
Redundant and other "negligible" risks do not exceed 0.001 probability of loss.

TABLE B. 3-2

POWER SUBSYSTEM COMPONENT CRITICALITY DETERMINATION DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
P1	Radioisotope Generator	Negl.	275	Negl.	3	10,000	Negl.	2
P2	"Primary" Batteries	50	50	0.0025	2	4,400	0.220	2
P3	RTG SHORT/ON Relay	Negl.	Negl.	Negl.	3	Negl.	Negl.	2
P4	Series Regulators	Red't	50	Negl.	3	1,300	Negl.	3
P5	Shunt Regulators	Red't	50	Negl.	3	10,000	Negl.	3
P6	Charge Regulators	Red't	50	Negl.	3	4,400	Negl.	3
P7	Charge Relays	Negl.	Negl.	Negl.	3	Negl.	Negl.	3
P8	Bus Relays	Negl.	Negl.	Negl.	2	Negl.	Negl.	3
P9	Buses #1 and #2	Negl.	50	Negl.	2	4,400	Negl.	3
P10	28 VDC Bus	Negl.	50	Negl.	3	3,100	Negl.	3
P11	DC/DC Conv/Regl	Red't	50	Negl.	3	10,000	Negl.	3
P12	RTG L/C Filters	Red't	50	Negl.	3	10,000	Negl.	3
P13	Bus Select Switches	Negl.	Negl.	Negl.	3	NA	NA	NA
P14	BATT TEMP Lamps	Negl.	Negl.	Negl.	3	NA	NA	NA
P15	BATT VOLT Lamps	Negl.	Negl.	Negl.	3	NA	NA	NA
P16	Deployment Battery	25	Negl.	Negl.	2	NA	NA	NA
P17	BATT AMP/Hr Sensors	10	50	0.0005	3	4,400	0.044	3

Notes: Red't - Redundant; Negl. - Negligible; NA - Not Applicable
Redundant and other item "negligible" risks do not exceed 0.001 probability of loss.

7456-FE

FOLDOUT FRAME

7456-FF

FOLDOUT FRAME

TABLE B.3-3

COMMUNICATIONS SUBSYSTEM COMPONENT CRITICALITY DETERMINATION DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
C1	Dir. Ant. & MW Network	Negl.	15	Negl.	2	3,100	Negl.	2
C2	Dir. Ant. and Servo Control	20	15	0.0003	2	3,100	0.062	2
C3	Omni Ant & Diplexer	Negl.	50	Negl.	3	10,000	Negl.	2
C4	Omni Diode Switch	Negl.	50	Negl.	3	10,000	Negl.	3
C5	S-Band Receivers	Red't	50	Negl.	3	10,000	Negl.	3
C6	Command Decoders	Red't	15	Negl.	3	3,100	Negl.	3
C7	Subsystem Decoders	Red't	15	Negl.	3	3,100	Negl.	3
C8	Dir. Ant. Diplexer	Negl.	15	Negl.	2	3,100	Negl.	2
C9	Dir. Link Combiner	Negl.	15	Negl.	2	3,100	Negl.	2
C10	FM Power Amplifier	Red't	50	Negl.	3	3,100	Negl.	3
C11	FM Exciter	Red't	50	Negl.	3	3,100	Negl.	3
C12	PM Power Amplifier	Red't	50	Negl.	3	3,100	Negl.	3
C13	PM Exciter	Red't	50	Negl.	3	3,100	Negl.	3
C14	Mod Processor	Red't	50	Negl.	3	3,100	Negl.	3
C15	VHF Antenna	Negl.	15	Negl.	2	NA	NA	NA
C16	VHF Triplexer	Negl.	15	Negl.	3	NA	NA	NA
C17	VHF Transmitter	Red't	15	Negl.	3	NA	NA	NA
C18	VHF Receiver	Red't	15	Negl.	3	NA	NA	NA
C19	Telemetry	Red't	50	Negl.	3	3,100	Negl.	3
C20	Comm N/BU Switch	Negl.	Negl.	Negl.	3	NA	NA	NA
C21	Comm Mode Switch	Negl.	Negl.	Negl.	3	NA	NA	NA

Notes: Red't - Redundant; Negl. - Negligible; NA - Not Applicable
Redundant and other item "negligible" risks do not exceed 0.001 probability of loss.

7456-FG

TABLE B.3-4

NAVIGATION SUBSYSTEM COMPONENT CRITICALITY DETERMINATION DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
N1	Vertical Gyro	95	15	0.0014	3	3,100	0.295	2
N2	Directional Gyro	70	15	0.0011	2	3,100	0.217	2
N3	NAV Computer	123	15	0.0018	2	NA	NA	NA
N4	ODOM S&C Circuits	5&Red't	15	0.0001	2	1,300	Negl.	3
N5	NAV Analog MUX	Red't	15	Negl.	3	3,100	Negl.	3
N6	NAV A/D Converter	Red't	15	Negl.	3	3,100	Negl.	3
N7	NAV PWR Conditioner	Red't	15	Negl.	3	3,100	Negl.	3
N8	BRG Display	Negl.	15	Negl.	3	NA	NA	NA
N9	NAV Data Display	Negl.	15	Negl.	3	NA	NA	NA
N10	NAV Display Switches	Negl.	Negl.	Negl.	3	NA	NA	NA
N11	GYRO MALF Lamps	Negl.	Negl.	Negl.	3	NA	NA	NA

Notes: Red't - Redundant; Negl. - Negligible; NA - Not Applicable
Redundant and other item "negligible" risks do not exceed 0.001 probability of loss.

7456-FH

TABLE B.3-5

REMOTE CONTROL AND HAZARD DETECTION COMPONENTS CRITICALITY DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
RC1	TV Camera and Electronics	200	4	0.0008	3	3,100	0.620	2
RC2	TV Position Controls	50	4	0.0002	3	3,100	0.155	2
RC3	M Range Hazard Radar	20	NA	NA	NA	1,300	0.026	3
RC4	S Range Hazard Radar	20	NA	NA	NA	1,300	0.026	3

7456-FI

TABLE B.3-6

CONTROL AND DISPLAY COMPONENT CRITICALITY DETERMINATION DATA

FMEA Code	Component Item Descriptions	Failure Risk x 10^{-6}/hr	Manned Mission Mode			Remote Control Mission		
			Operate Hours	Total Risk	Failure Effect	Operate Hours	Total Risk	Failure Effect
A1	Warning Lamps, C&D Panel	Negl.	Negl.	Negl.	3	NOT APPLICABLE		
A2	Toggle Switches, C&D Panel	Negl.	Negl.	Negl.	3			
A3	Toggle Switches, AUX Panel	Negl.	Negl.	Negl.	3			
A4	Hand Control Electronics	Red't	15	Negl.	3			
A5	NAV BRG and Data Displays	Red't	15	Negl.	3			

Notes: Red't - Redundant; Negl. - Negligible; NA - Not Applicable
Redundant and other item "negligible" risks do not exceed 0.001 probability of loss.

7456-FJ

It is significant to note that there are no known Category 1 astronaut risk of life failure mode items in the component summary tables.

The failure fisks identified in the component summary tables are based on parts complexity and parts failure rate estimates derived from previous Bendix lunar vehicle reliability studies for the MOLAB, LSSM, Specified LSSM, and other vehicle study reports previously submitted to MSFC. In general, the parts failure rates are conservative using MIL-HDBK-217 and MIL-HDBK-217A data and estimating techniques. The use of current state-of-the-art high reliability parts and/or MSFC-preferred parts with screening/burn-in techniques would reduce failure risks well below the provided estimates.

Operating time for the DLRV components are shown in the tables based on the assumptions set forth in Section B. 3. 2. The component failure rates and operating times for all components of a category, i. e. , for six TDMs, were combined to establish the total mission risk for each category of component: (1) in the manned mode, and (2) in the remote mode missions.

The equipment items which are fully redundant on DLRV are listed as "Red't" in Tables B. 3-1 through B. 3-6. Preliminary reliability calculations have shown all these items to have a probability of less than 0.001 that both would fail during manned or unmanned mode missions. Also, items which have a failure rate on the order of 0. 00001 for the manned mission and/or on the order of 0. 000001 or less per hour in the remote mission were listed as "negl. " or neglible probability of failure risks.

B. 3. 5 Critical Components, Manned Mission

B. 3. 5. 1 Mobilility Subsystem

Based on the data shown in Table B. 3-1, there are two Category 2 component failure modes which could significantly degrade the manned mission, and 13 Category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system, except for the unknown actuation on wheels.

The M5 EMER/PARK Switch and the M8 Shock Dampers represent the two Category 2 hazards. The loss of the M5 brake switch is classified as a degraded mode condition due to the loss of real-time responses which may be required by the astronaut in the event of an emergency. The function of the M5 switch may be accomplished by remote control; however, the 2. 6-second moon/earth/moon communication delay is considered for a situation where the brake may be needed immediately during the negotiation of a crevasse, maximum slope, or maximum obstacle condition. If the mission speed and maneuver actions are reduced after switch loss, remote control may be used for a safe degraded mission capability.

The loss of the M8 shock damper is classified as a Category 2 item, considering that the astronaut is expected to reduce his speed significantly below 15 km/hr on rough surfaces where small obstacles are frequently encountered which would result in a reduction of total travel within the allowed sortie operation time.

The M11 TDM Assemblies, M9 TDM Controllers, M13 TDM/SDM Power Conditioners, M12 SDM Assemblies, and M10 SDM Controllers are Category 3 items which have the most likely probability of failure during manned mode operations; however, the risks for single-item failures is less than 2% for any item, and the risk of two or more item failures is considered negligible.

All other Category 3 items are of secondary importance for low operating time, cycle, failure rate and the operational backup considerations explained in the Section B.5 FMEA data sheets.

B.3.5.2 Power Subsystem

Based on the data shown in Table B.3-2, there are four Category 2 component failure modes that could significantly degrade or impact the manned mission and 13 Category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system.

The P2 Primary Batteries, the P8 Bus Relays, the P9 Buses No. 1 and No. 2, and the P16 Deployment Battery represent the four Category 2 hazards for the manned mode mission. The primary batteries have the only significant probability (0.25%) that one of the two might fail during manned operations.

The loss of a primary battery at the beginning of sortie No. 1 would still provide power for two full 30-km sorties; however, the possibility of a second battery failure would restrict the radius of vehicle operation to walk-back range for astronaut safety.

The loss of bus relay or buses in the redundant mobility power distribution system would not reduce the capability of the vehicle to perform full vehicle sorties after proper switching of mobility loads. However, the possibility of additional failures which would immobilize the vehicle is considered to require that the radius of vehicle operation be reduced to walk-back range for astronaut safety.

The possible failure of the Deployment Battery could (1) prevent the manned mission from being started, or (2) result in considerable astronaut effort and loss of mission time to physically move the unpowered DLRV fore and aft sections together for proper mating and checkout.

The remaining 13 Category 3 Power Subsystem failure modes listed in Table B.3-2 are items which have redundancy or mission effective alternate mode backup capabilities to offset the effect of initial failures. The applicable backup capabilities or compensating procedures are described in the FMEA sheets of Section B.5.

B.3.5.3 Communications Subsystem

Based on the data shown in Table B.3-3, there are five Category 2 failure modes that could significantly degrade the manned mission and 16 Category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system.

The loss of C1 and C2 Directional Antenna and Servo, C8 and C9 Directional Link Diplexer and Combiner, and the C15 VHF Antenna are the only Category 2 items. The loss of the directional link functions would cause the mission to be performed with the omni link capability, allowing voice and telemetry but no biomed data, and reduce the rate of transmission of TV and facsimile camera frames. Television frames may require 65 minutes; 360° facsimile may require 30 minutes per frame using omni link capability in the event of directional link loss. The highly unlikely loss of the vehicle's VHF whip antenna would cause the mission to be reduced to radio LOS operating radius with the LM for astronaut communication to earth.

All other FMEA items are Category 3 and have a minor effect as explained in the Section B.5 FMEA data sheets.

B.3.5.4 Navigation Subsystem

Based on the data shown in Table B.3-4, there are three Category 2 failure mode hazards which could significantly degrade the manned mission and eight category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system.

The N2 Directional Gyro, the N3 Navigation Computer, and the N4 Odometer Selection and Counter Circuits represented the three Category 2 hazards.

The loss of the directional gyro would result in vehicle inability to compute and display navigation data on the vehicle and loss of gyro data needed for ground backup computation. The effect would cause the astronaut to reduce his sortie operations to LM LOS and adjacent areas which are acceptable for landmark recognition.

The loss of the vehicle Navigation Computer results in the loss of operating navigation data on the DLRV displays. However, earth-based navigation using vehicle telemetry data from the vehicle navigation sensor may be used to radio relay position bearing and distance data to the astronaut who may continue a less effective but practical degraded mission with or without landmarks.

The loss of Odometer Selection and Counting circuits is not recognized and compensated for in the vehicle navigation computer. However, earth-based navigation using vehicle odometer data can discriminate and correct navigation errors. In such an event, the astronaut would operate with earth-furnished navigation data as he would for the loss of the vehicle navigation computer.

The other 13 Category 3 failure mode hazards are of secondary importance based on the redundancy or alternate mode backup considerations which are explained in the Section B.5 FMEA data sheets.

B.3.5.5 Controls and Displays

Table B.3-6 identifies five categories of warning lamps, C&D panel switches, auxiliary panel switches, hand control electronics, and the navigation display items which are directly employed by the astronaut during the manned mode mission.

In general, all these items are Category 3 and have a minor effect on mission hazards because of functional alternate mode redundancy or remote control backup telemetry monitoring and switching capabilities explained in the Section B.5 FMEA data sheets.

One park brake switch discussed under the Mobility Subsystem and loss of navigation displays due to sensors malfunctions are Category 2 special cases previously discussed.

B.3.5.6 System Summary, Manned Mode

Subsystem Nomenclature	Category 2 FMEA Items	Category 3 FMEA Items
Mobility	2	13
Power	4	13
Communications	5	16
Navigation	3	8
Control/Display	-	3
Total	14	53

B.3.6 Critical Components, Unmanned (Remote) Mission

B.3.6.1 Mobility Subsystem

Based on the data shown in Table B.3-1, there are no Category 2 components whose first failure would significantly degrade the remote mission, with the possible exception of the wheel element rings. However, there are 10 other Category 3 items which would have a minor effect due to redundancy or other alternate mode backup capabilities in the system.

The loss of wheel ring elements may become a degraded mode consideration, depending on the fatigue life characteristics established during the development test program. Even with a marginal fatigue life design, the 20 ring elements and ring bumper features of each wheel would allow extensive ring failures to occur before the 2-km/hr unmanned traverse capabilities of the vehicle were seriously degraded. Slope and obstacle capabilities of the vehicle would be the first characteristics affected in the event of multiple ring failures.

The most likely Category 3 mobility component failures in descending order of probability are: the TDM assemblies, TDM controllers, TDM/SDM power conditioners, SDM assemblies, and SDM controllers. The functionally divided capabilities, fault isolation, and decoupling features of the DLRV design render the vehicle relatively insensitive to the first of each of these component losses, and still provide additional degraded mode capability for two or more such failures before the remote DLRV mission is significantly degraded.

The balance of five Category 3 failure mode items are low-risk and secondary importance mission effect items as explained in the Section B.5 FMEA data sheets.

B.3.6.2 Power Subsystem

Based on the data shown in Table B.3-2, there are three Category 2 component failure modes which could significantly degrade the remote mission; there are 10 Category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system.

The Category 2 items are the RTG, Primary Batteries, and the RTG Short/On Relay.

The loss of the RTG would result in the mission being terminated as soon as the vehicle batteries were expended following the loss of the RTG charging source. Considering the series-parallel design of the RTG thermoelectric elements, the loss of the RTG is very unlikely.

The loss of one of two primary batteries is a significant mission risk on the order of 22% probability for the full mission duration, and the effect would be more charge delays to complete the mission. There is a choice of: (1) operating the vehicle more slowly after battery loss, or (2) modifying the MCC schedule to allow for twice as many recharges during the operational routine. At a vehicle speed of 0.5 km/hr on smooth terrain, the 15-hr operate and 9-hr recharge cycle routine may be maintained. At 1.0 km/hr, two recharge cycles per earth day will be required.

The loss of RTG Short/On relay would terminate the mission shortly after malfunction as for the loss of an RTG. Redundant contacts for the RTG-On condition (made initially before the remote mission by a latching relay) should, however, represent a negligible risk of mission failure.

The 10 Category 3 failure mode items in the Power Subsystem, except for the Battery Amp-Hour Sensors, are low-risk items whose failure mode effects are minor as explained in the Section B.5 FMEA data sheets.

B.3.6.3 Communications Subsystem

Based on the data shown in Table B.3-3, there are five Category 2 component failure modes which could significantly degrade the remote mission, and there are nine Category 3 items which would have a minor effect due to redundancy or alternate mode backup capabilities in the system.

The Category 2 items are the C1 Directional Antenna and Microwave Network, the C2 Directional Antenna Servo Control, the C3 Omni Antenna and Diplexer, the C8 Directional Antenna Diplexer, and the C9 Directional Antenna Combiner.

The loss of the directional link components would seriously degrade the vehicle's ability to transmit TV and facsimile camera data for the DLRV remote control driving operations. Limited step mode travel would be possible with very low frame rates transmitted via the omni link with serious impact on time to complete the mission.

The loss of the omni antenna would result in the need to maintain the directional link operating in the receiving mode at all times to accept earth commands and use added power for telemetry during all operational periods. Moreover, the inadvertent loss of directional antenna aiming in such a condition will terminate communications with the vehicle unless an automatic search on the DLRV is provided in the development design.

The remaining nine Category 3 failure mode items are low-risk items and have a minor effect on the mission as explained in the Section B.5 FMEA data sheets.

B.3.6.4 Navigation Subsystem

Based on the data shown in Table B.3-4, there are two Category 2 failure mode items that could significantly degrade the remote mission and four Category 3 items which would have a minor effect due to redundancy or alternate mode backup considerations.

The Category 2 items are represented by the loss of the H1 Vertical Gyro and/or the loss of the N2 Directional Gyro. Moreover, these are the only two items which have significant probabilities of failure, 29.5 and 21.7%, respectively, for the mission period.

The loss of the vertical gyro will result in the loss of vehicle attitude data required for TV picture synchronization at the MCC ground station, and additional navigation updates using landmark recognition checks. System capability may be reduced to step mode operation.

The loss of the directional gyro will significantly degrade MCC ground station tracking of the vehicle during traverse and reduce the navigation capability to dependency on landmark recognition. Heading references required by the vehicle for the normal steering mode will not be available to the DLRV steering logic, and wheel angle position commands must be employed.

The remaining four Category 3 minor effect failure modes are explained in the Section B.5 FMEA data sheets.

B.3.6.5 Remote Control and Hazard Detection

Based on the data shown in Table B.3-5, there are two Category 2 failure mode items that could significantly degrade the remote mission and two Category 3 items which would have a minor effect due to redundancy and alternate mode backup considerations.

The Category 2 items are represented by the loss of the RC1 TV Camera and Electronics and the RC2 TV position controls.

The loss of the TV camera is a significant probability estimated at a risk of 62% for the period of the mission. The facsimile camera may be used as a step mode backup with greater dependency on IR hazard detection sensors but at a sacrifice in mission time and effectiveness.

The loss of the TV camera position controls (15.5% risk) may also result in the loss of continuous mode driving capability employing the facsimile camera as a step mode backup. However, if the TV azimuth or elevation controls can be fixed on the vehicle forward path by backup mode control release mechanisms, continuous mode use of TV may be feasible with some loss in operating flexibility.

The Category 3 IR hazard radar sensors may independently fail with a minor effect on the remote mission. The loss of the medium-range unit may be effectively offset by more deliberate use of TV at the nominal 15-m range in the continuous mode of operation. The loss of the short-range sensor may be offset by the command conversion of the medium-range unit for operation at the short 2-m nominal range.

B.3.6.6 System Summary, Unmanned (Remote) Mode

Subsystem Nomenclature	Category 2 FMEA Items	Category 3 FMEMA Items
Mobility	-	10
Power	3	10
Communications	5	9
Navigation	2	4
Remote Control	2	2
Total	12	35

B.4 DLRV FMECA STUDY RECOMMENDATIONS

B.4.1 Design and Analysis

Based on FMECA analysis of the Phase B preliminary design, the following suggestions have been generated for development phase considerations:

1. Redundant Directional Gyros
2. Redundant Vertical Gyros
3. Redundant TV Vidicons
4. Redundant TV Position Controls

5. Redundant Directional Antenna Servos

6. Automatic Search Mode provisions for the Directional Antenna

7. Design of DLRV to allow acceptance checkout of all redundant or alternate mode backup capabilities at final assembly

8. FMEA of development phase detailed design down to the level of all discrete parts and materials

9. FMEA of development phase detailed wiring, cabling, terminals, and connectors employing MSFC procedures devised for this purpose

10. Based on the development study phase FMECA, generate and maintain "Lists of DLRV Critical and Limited Life Components, Parts and Materials."

B.4.2 Development Test and Control

1. Perform and evaluate fatigue life tests of DLRV wheels, wheel ring elements, and flexible wheel rims. Test under simulated lunar soil and terrain roughness conditions for normal and degraded mode life capabilities.

2. Perform and evaluate fatigue life tests of suspension shock damper mechanisms as individual units in the normal mode. Test under mission profile spectrum of vehicle motions on the lunar surface. Employ vacuum conditions.

3. Perform and evaluate mission profile endurance life tests of TDM and SDM units mated with controllers to evaluate life characteristics of all included mechanical, electrical, seal, and lubricant elements.

4. Perform and evaluate life tests of DLRV batteries including mission spectrum loads profile. Employ temperature range and wet stand time conditions.

5. Perform and evaluate life tests of DLRV directional antenna servo control mechanisms, TV vidicon and servo control mechanisms, navigation vertical and directional gyros, and IR hazard radar sensors. Employ mission spectrum duty cycle profiles and thermal control range variations.

6. Select electrical, electromechanical, and electronic parts and components from MSFC-preferred standards, or if not feasible, employ high reliability standards based on functional/environment/defect screening and burn-in controls equivalent to MSFC-preferred item process.

7. Generate and maintain DLRV project Preferred Parts Materials and Components Lists (based on Item 6) to serve as a standard guide for DLRV selection and as a record of vehicle and operational GSE use.

B.4.3 Reliability and Safety Programs

Specific reliability and safety programs tailored to the DLRV design, development program nature, and safety/reliability considerations have been proposed. These plans are outlined in Vol II, Book 4 of this report.

B.5 SUBSYSTEM FMEA ANALYSIS SHEETS

B.5.1 Manned Mode Mission Data

The following DLRV Manned Mission Failure Modes and Effects Summary Sheets are included as tables in this subsection:

Table B.5-1	Mobility Subsystem (2 sheets)
Table B.5-2	Power Subsystem (2 sheets)
Table B.5-3	Communications Subsystem (3 sheets)
Table B.5-4	Navigation Subsystem (2 sheets)
Table B.5-5	Astronaut Controls and Displays (1 sheet).

TABLE B.5-1

DLRV MANNED MISSION FAILURE MODE AND EFFECTS SUMMARY SHEET MOBILITY SUBSYSTEM

ITEM	COMPONENTS	ASSUMED FAILURE MODES	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
M1	AFT Unit Connections	Loss of power connector or wiring redundancy.	No effect on mission. Design intent is to provide complete Power and critical functional wiring redundancy in separate cables.	None required
M2	Hand Control	Loss of Speed, Steering, or brake inputs to mobility control in manned mode.	No effect on mission for single resolver failures. Backup resolvers and control circuits on control assembly automatically compensate.	In the event of second or redundant resolver failure, remote control is capable of providing emergency functions.
M3	Foreward/Reverse Switch (C&D Panel)	Loss of manual switch in foreward or reverse mode or both.	Minor effect on mission. Effect is critical only in event of uplink loss.	Remote control system provides for normal mode operations and for backup mode if necessary.
M4	Hi-Lo Transmission Gear Shift Switch (C&D Panel)	Loss of manual switch in high, low or both switch modes.	Minor effect on mission. Loss is critical only in event of uplink loss.	Remote control system provides switching for normal mode operations and for backup mode if necessary.
M5	Emergency/Park Brake Switch (C&D Panel)	Loss of manual switch in on, off or both switch modes.	Mission is degraded. Loss of real time emergency braking. Three modes of dynamic braking are still effective. Critical for crevasse and obstacle negotiation	Remote control system provides backup for effective parking or degraded mode (time delayed) emergency stop action.
M6	TDM Temp/Current Warning lamps (C&D Panel)	Loss of visual indicator, sensor or signal conditioning for one or more TDM units.	No effect on manned sortie operations unless actual TDM malfunction occurs, or if communication link loss occurs.	Remote Telemetry monitoring of TDM and Mobility System will inform astronaut of true status.
M7	Wheel Assemblies	Fatigue failure or damage of discrete element rings.	Negligible or minor effect during short manned mission. Wheels capable of emergency return on rim structure.	Periodic or between sortie walkaround inspection by astronaut will indicate operating cautions, if needed.
M8	Shock Dampers	Functional loss of 1 or more dampers.	Degraded damping function for affected wheels. Dampler limit stops and snubbers will restrain suspension arms. Speed may be reduced for overall sortie mission.	Astronaut may reduce speed to limit bottoming shock on degraded dampers or to reduce discomfort. Obstacle negotiation will require greater attention to prevent difficulty.

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TABLE B.5

DLRV MANNED MISSION FAILURE MODE AND EF

ITEM	COMPONENTS	ASSUMED FAILURE MODES
M9	TDM Power Controller Channels	Loss of 1 or more of 6 TDM controller channels.
M10	SDM Power Controller Channels	Loss of 1 or more 4 SDM power controller channels.
M11	Traction Drive Mechanisms (TDM's)	Loss of drive motor (1 of 6) Loss of transmission (1 of 6)
		Loss of 2 or more TDM motors or transmissions
M12	Steering Drive Mechanisms (SDM's)	Loss of 1 of 4 SDM motors or transmissions.
M13	TDM/SDM Power Conditioners	Loss of 1 of 6 or more TDM/SDM channel functions. Loss of 1 of 4 SDM channel functions.
M14	TDM & SDM power circuit breaker relays or manual power switches	Loss of 1 or more circuit breaker relay or power switch functions.
M15	Dynamic Stability Warning	Loss of lamp indicator or threshold electronics (hazard warning logic).

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FECTS SUMMARY SHEET MOBILITY SUBSYSTEM

FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
Minor or degraded mission effect depending on number of malfunctions and lunar traverse conditions.	TDMs may be mechanically and electrically decoupled by the astronaut or remote control to allow free wheeling.
Minor or degraded mission effect depending on number of malfunctions and lunar traverse conditions.	SDMs may be mechanically and electrically decoupled by the astronaut or remote control to allow wheels to free castor or be locked in fixed position if desired.
Minor. Mission may be continued with minor effect on speed and obstacle performance capability.	TDMs may be mechanically and electrically decoupled by the astronaut or remote control to allow free wheeling.
Degraded mission or emergency return depending on number of malfunctioning units and lunar traverse conditions.. Detours and time delays may result	Same as above. More than one TDM failure may force driver to avoid the more severe slope and obstacle conditions.
Minor. Mission may be continued with negligible effect on mobility performance and control except in reverse driving.	SDM's may be mechanically and electrically decoupled by astronaut or remote control to allow wheels to free castor or to lock in fixed position if desired.
Minor or degraded mission effect depending on the number of malfunctions and lunar traverse conditions.	Both TDM and SDM for a given wheel must be electrically and mechanically decoupled by manual or remote control means.
Open CCBs will result in minor or degraded mission effect depending on number and traverse conditions. Detours and time delays may result depending on TDMs or SDMs disabled.	CCBs or switches which cannot be reset by remote control will result in corresponding TDM or SDM decoupling procedures.
Minor effect on mission. Audio warnings are redundant with lamp warnings.	Audio warning and pitch/roll angle angle sensing off vertical gyro will provide audio warning via VHF vehicle transmitter.

TABL

DLRV MANNED MISSION FAILURE MODE AND E

ITEM	COMPONENTS	ASSUMED FAILURE MODES
P1	RTG (130 Watts)	Local Internal open or short malfunctions. (Thermoelectric couples are series-parallel ladder networks).
P2	"Rechargeable" AG-ZN Batteries Units A & B.	Loss of 1 of 2 batteries during sortie traverse.
P3	RTG Short/On Relay	Loss of function in short or in on positio
P4	Switching Series Regulator	Loss of functions for 1 of 2 redundant units.
P5	Switching Shunt Regulator	Loss of function for 1 of 2 redundant units.
P6	Charge Regulators #1 & #2.	Loss of functions - 1 of 2 redundant units
P7	Charge Mode relays #1 & #2.	Open or short

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FFECTS SUMMARY SHEET POWER SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Minor effect. Loss of normal power source for astrionics, science, controls & displays and DLRV heaters will be offset by primary batteries	Switching shunt regulator automatically supplies 28V buss for astrionics, by driving power from primary batteries.
	Mission degraded. Each battery is sized to provide for emergency return of at least 10 km from LM if battery should fail at worst case condition during the 4th sortie.	All battery laods may be switched manually or by remote control to good battery for DLRV operation within astronaut walkback range.
a.	Short or open mode loss prevented by manual backup switch. Loss of ON function will degrade mission same as for RTG loss.	Switching shunt regulator will automatically provide 28V buss power required from batteries in degraded mode mission.
	No effect on mission. Standby redundant unit will automatically provide interbuss regulation.	None required unless both series regulators fail. Second failure will degrade but not abort power subsystem.
	No effect on mission. Standby redundant unit will automatically provide RTG load regulators	None required unless both shunt regulators fail. Second failure will reduce system to operation on batteries plus RTG power provided through charge regulators .
.	Minor effect on mission. Rate of battery recharge will be increased using one unit to charge each of 2 batteries alternately.	MCC may switch RTG power from one battery to another to balance energy return to both batteries if needed.
	Minor effect on mission. Open failure mode will affect mission same as above. Shorted contacts will not affect normal functions.	Same as above (P6) except that shorted contacts will require no action.

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TABLE B.5

DLRV MANNED MISSION FAILURE MODE AND E

ITEM	COMPONENTS	ASSUMED FAILURE MODES
P8	Battery-Buss Select Relays #1 & #2.	Open or short
P9	Mobility Busses #1 & #2.	Open or short
P10	28 Volt Buss	Open or short
P11	DC-DC Converter Regulator	Loss of functions for 1 of 2 redundant units.
P12	RTG LC Filters	Open failure for 1 of 2 redundant units
P13	Buss Select and OFF Charge Switches (C&D Panel)	Open or short modes
P14	Battery Temperature Warning Lights and Redline Logic (C&D Panel)	Loss of functions
P15	Battery voltage Warning Lights and Redline Logic. (C&D Panel)	Loss of functions
P16	Deployment Battery	Self discharge or open circuit conditi

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¡-2 (Cont.)

'FFECTS SUMMARY SHEET POWER SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Open failure mode will put all mobility loads on 1 buss. Short failure mode will constrain buss switching.	Manned traverses may be reduced to walkback radius to prevent crew loss in the event of additional failure.
	Open failure mode will put all mobility loads on 1 buss. Short failure will have the same effect.	Manned traverses may be reduced to walkback radius to prevent crew loss in the event of additional failures.
	Redundant wiring, spacing and insulation techniques plus diode or fuze protection to all loads prevent failure. Possible malfunction are expected to be on loads and localized in loads.	None. Redundancy and circuit protection provisions are automatic compensations. Load malfunction effects and compensations will depend on loads defined elsewhere.
	No effect on mission. Parallel redundant unit will automatically provide unit decoder and telemetry power and regulation.	None required unless both units fail. Loss of remote control and telemetry backup would reduce safety but not capability of manned mission.
ı.	No effect on mission. Parallel redundant unit will automatically provide 28 volt buss power.	None required unless both units fail. Second failure will cause minor loss of RTG power being provided through charger battery and series regulator.
	Astronaut unable to change mode for affected battery select for charge mode functions. Critical only if communication links are lost.	Remote control may provide backup function to activate charge mode relays or buss select relays.
	Loss of real time warning on DLRV. Critical only in the event that communication links are lost.	Remote control telemetry provides backup data which may be relayed via S-band uplink.
	Loss of real time warning on DLRV. Critical only in the event that communication links are lost.	Remote control telemetry provides backup data which may be relayed via S-band uplink.
ın.	Four wheel section cannot be driven to aft unit for mating after unloading operations.	Two astronauts must pull two wheel aft section over to four wheel section for mating and four wheel unit must be pulled into mating position.

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TABLE

DLRV MANNED MISSION FAILURE MO
COMMUNICATIO

ITEM	COMPONENTS	ASSUMED FAILURE MODES
C1	Directional Antenna and Microwave Network	Loss of Transmitting capability
C2	Directional Antenna Drive	Loss of azimuth and/or elevation drive functions.
C3	Omni Antenna and Diplexer	Loss of transmitting and/or receiving capability.
C4	Omni Diode Switch	Loss of Omni or S-band input, or receiv output functions.
C5	S-Band Receivers	Loss of 1 of 2 redundant receivers.
C6	Command Decoders	Loss of 1 of 2 redundant system decoder
C7	Subsystem Decoders	Loss of mobility, power, science or astrionics decoder functions.
C8	Directional Link Diplexer	Loss of input/output functions.

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B.5-3

ES AND EFFECTS SUMMARY SHEET
NS SUBSYSTEM

	EFFECT ON MISSION	OPERATIONAL COMPENSATIONS
	Degraded mission. Reception of uplink not affected. Loss of biomed data and 30% of voice quality. TV transmission is severely restricted.	Omni antenna will handle all uplink data and downlink voice. TV frames require 6.5 minutes; 360° FAX requires 30 minutes per frame.
	Degraded mission. Reception of uplink not affected. Loss of biomed data and 30% of voice quality. TV transmission is severely restricted.	Continue mission without biomed data and TV except when the vehicle maneuvering can compensate azimuth loss or elevation
	Minor effection mission. All uplink and downlink FM and PM data may be handled by directional S-band. If directional antenna loses ground station, communication will cease until astronaut moves DLRV.	Directional S-band must be operated continuously for astronaut voice and biomed data. Addition of search mode would automatically lock on to ground station.
er	Minor effect in mission. Results in loss of ability to switch receiver and antenna combination.	Astronaut may be required to manually switch between communication service modes occasionally.
	No affect on mission. Standby redundant receiver will function for either omni or directional link modes.	Switching between receivers is automatic if one fails. Failure of both causes emergency return to LM VHF operating radius. (VHF line of sight).
s.	No effect on mission. Standby redundant decoders will function for either omni or directional link modes.	Switching of decoders is automatic. Failure of both would remove remote control backup functions.
	No effect on mission. Loss of specific decoders unlikely because of actual or functional redundancy.	Remote control status monitoring will advise astronaut of reduction in backup flexibility.
	Degraded mission. Reception of uplink and transmission of downlink may be limited to Omni capabilities. (See Item C-1).	See mission compensation for Item C1, Directional Antenna and Microwave Network.

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TABLE B.5

DLRV MANNED MISSION FAILURE MO
COMMUNICATIO

ITEM	COMPONENTS	ASSUMED FAILURE MODES
C9	Directional Link Combiner	Loss of functions.
C10	FM Power Amplifier	Loss of functions for 1 of 2 redundant u
C11	FM Exciter	Loss of functions for 1 of 2 redundant u
C12	PM Power Amplifier	Loss of functions for 1 of 2 redundant u
C13	PM Exciter	Loss of functions for 1 of 2 redundant u
C14	Modulation Processor	Loss of functions for 1 of 2 redundant u
C15	VHF Whip Antenna	Loss of transmit or receive capability.
C16	VHF Triplexer	Loss of isolated input or output functio

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DES AND EFFECTS SUMMARY SHEET
NS SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Degraded mission. Transmission of down-link may be limited to Omni capability.	See mission compensation for Item C1, Directional Antenna and Microwave Network.
nits.	No effect on mission. Standby redundant Amplifier will operate for either Omni or Directional links.	Switching between Amplifier units may be done by astronaut "C" mode switch or by remote control.
nits.	No effect on mission. Standby redundant Exciter will operate for either Omni or Directional links.	Switching between Exciter units may be done by astronaut "C" mode switch or by remote control.
nits.	No effect on mission. Standby redundant Amplifier will operate for either Omni or Directional links.	Switching between Amplifier units may be done by astronaut "C" mode switch or by remote control.
nits.	No effect on mission. Standby redundant Exciter will operate for either Omni or Directional links.	Switching from primary to standby Exciter is automatic when PM Power Amplifier is switched.
nits.	No effect on mission. Standby redundant Processor will handle all voice, biomed and TM data.	Switching from primary to standby Processor is automatic when PM Power Amplifier is switched.
	Degraded mission. DLRV operator would be unable to transmit to MCC or receive MCC or receive DLRV audio warnings.	DLRV mission is reduced to VHF line of sight with LM. Emergency key may be used to inform MCC of crew well being.
ns.	Minor effect if redundant transmitter or receiver functions are lost. Degraded mission per item C-15 if antenna interface is lost.	Redundant VHF transmitter or receiver function will be used by astronaut. If VHF antenna is affected, mission area is re-duced to VHF line of sight with LM.

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TABLE B.5

DLRV MANNED MISSION FAILURE MO
COMMUNICATIC

ITEM	COMPONENTS	ASSUMED FAILURE MODES
C17	VHF Transmitters	Loss of 1 or 2 of redundant VHF transmitters on DLRV.
C18	VHF Receivers	Loss of 1 or 2 of 3 redundant VHF receiv on DLRV.
C19	DLRV Borne Telemetry	Loss of isolated measurements.
		Loss of power supply or multiplex/conve functions.
C20	Communications Normal-Backup Switch (C&D Panel)	Loss of function.
C21	Communications Mode-Select Switch (C&D Panel)	Loss of function.

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-3 (Cont.)

DES AND EFFECTS SUMMARY SHEET
)NS SUBSYSTEM

	EFFECT ON MISSION	OPERATIONAL COMPENSATION
	Minor effect on mission. Either of 2 DLRV transmitter channels will provide uplink voice from MCC to astronaut.	Either of 2 MCC-to-astronaut uplinks available by vehicle communication mode switch. Failure of both VHF transmitters will reduce mission to VHF line of sight with LM.
ers	Minor effect on mission. Any of 3 VHF receiver channels will provide voice downlink to MCC.	Signal operated switch on DLRV will automatically restore downlink in event of isolated DLRV receiver failure.
	Minor effect on mission for loss of TM data since all critical measurements are functionally redundant or provided in real time to astronaut on display panel.	Loss of isolated measurements are detected by MCC remote control and increased monitoring of functionally redundant data will support mission and crew safety requirements.
rter	Minor effect based on redundancy of crew displays for real time critical functions.	Minor or significant loss of TM data will result in MCC monitoring of mission status and safety by voice communication with astronaut.
	Minor effect. Remote control relays provide functional backup for normal or alternate mode switching.	MCC remote control switching of any backup function based on TM monitoring or per astronaut request.
	Same as above. C-20.	Same as above. C-20.

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TABL

DLRV MANNED MISSION FAILURE MOD
NAVIGATION

ITEM	COMPONENTS	ASSUMED FAILURE MODES
N-1	Vertical Gyro	Loss of accuracy or malfunction
N-2	Directional Gyro	Loss of accuracy or malfunction
N-3	Navigation Computer	Loss of accuracy or malfunction
N-4	Odometer Selection & Counter Circuits	Loss of accuracy or malfunction
N-5	Analog Multiplexer	Loss of redundant functions.
N-6	A/D Converter	Loss of redundant functions

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E B.5-4

)ES AND EFFECTS SUMMARY SHEETS
SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Minor effect on sortie. Vertical gyro is not used for onboard computation. Loss of MCC ground navigation accuracy. Loss of vehicle attitude warning inputs.	MCC may perform more frequent ground navigation updates using landmark recognition. Vehicle stability sensing is degraded and may reduce vehicle speeds, if astronaut cannot judge stability.
	Mission degraded. Loss of all heading and position display data on DLRV indicators. Loss of MCC ability to provide backup navigation computation.	If landmark navigation by astronaut and MCC is not adequate for a given area, sorties may be reduced to visual line of slight with LM or adjacent areas where landmark recognition is effective.
	Degraded sortie mission. Navigation range and distance data on DLRV display would be degraded.	Remote control navigation computation and data may be provided verbally on communication links.
	Degraded sortie mission. Navigation range and distance data on DLRV display would be degraded.	MCC navigation computations may discriminate between good and malfunctioning odometers or circuits and relay good bearing range and distance data to astronaut for mission continuation.
	Minor effect on mission.	DLRV control & display panel will provide bearing and range navigation data.
	No effect on mission. Redundancy will automatically process gyro data for data display and TM use	None required unless all redundancy for gyro data is disabled and restrict mission to landmark recognition area limitations.

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TABLE B.5

DLRV MANNED MISSION FAILURE MO
NAVIGATION

ITEM	COMPONENTS	ASSUMED FAILURE MODES
N-7	Navigation Power Conditioning	Loss of 1 of 2 dual redundant sections
N-8	Bearing Display	Loss of function
N-9	NAV Data Display	Loss of functions
N-10	Bearing and NAV Data Display Select Switches	Loss of functions
N-11	Gyro Malfunction Indicator	Loss of function for indicator or sensing electronics

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-4 (Cont.)

DES AND EFFECTS SUMMARY SHEET
SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	No effect on mission. Standby redundant unit will automatically provide power and regulation to all NAV components.	None required unless both fail under short loading. Second failure may cause mission to be reduce to landmark recognition area capabilities.
	Minor effect on mission. NAV data display will provide bearing data.	Astronaut C&D panel switching or MCC may provide voice relay of bearing data based on navigation computations of TM data.
	Minor effect on mission. Range LM or site is lost on C&D panel.	MCC may provide voice relay of range data based on navigation computations of TM data.
	Minor effect on mission. Data display switching flexibility is lost on board DLRV.	MCC may provide voice relay of range or bearing data to astronaut based on earth navigation computations of TM data.
	No effect on mission unless actual gyro malfunction occurs.	MCC monitoring via telemetry will inform astronaut for emergency action if necessary.

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TABLE

DLRV MANNED MISSION FAILURE MOD
ASTRONAUT CONTR

ITEM	COMPONENTS	ASSUMED FAILURE MODES
A-1	Warning Lamps or Indicators, C&D Panel	(6) TDM Temp/Current Lamps (1) Dynamic Stability (2) Battery Volts (2) Battery Temperature (1) Gyro Malfunction (1) Bearing Indicator LM/SITE (2) Nav Data Display
A-2	Toggle Switches, C&D Panel	(1) Audio/Lamp Test Sw. (1) Panel Power/Lights Sw. (1) Bearing LM/Site Sw. (1) Emergency Key Sw. (1) Comm Normal/Backup Sw. (1) Emer/Park Brake Sw. (1) Hi/Low Gear Sw. (1) Fwd/Reverse Sw. (1) Manned/Remote Sw. (2) Batt. Buss Select Sw. (1) RTG On/Short Sw.
A-3	Toggle Switches, Auxiliary Panel	(6) TDM Power On/Off (4) SDM Power On/Off (6) TDM Decouple On/Off (4) SDM Decouple On/Off (4) TDM/SDM Buss Select (1) Deployment Battery On/Off
A-4	Control Stick, Manual	(1) Safety (grip) Switch (2) Speed/Brake Resolvers (3) Steering Angle Resolvers
A-5	Navigation Displays	(1) Bearing Display (1) NAV Data Display

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)E AND EFFECTS SUMMARY SHEET
)LS AND DISPLAYS

FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
Minor, TM Backup	See Item M-6
Minor, Audio Backup	See Item M-15
Minor, TM Backup	See Item P-14
Minor, TM Backup	See Item P-15
Minor, TM Backup	See Item N-14
Minor, TM Backup	See Items N-11 and N-13
Minor, TM Backup	See Items N-12 and N-13
Minor, Redundant sw. contacts	Earth TM monitor backup
Minor, Redundant sw. contacts	Redundant power source
Minor, Remote Control backup	See Item N-13
Minor, 3rd order backup loss	See Item C-15
Minor, Remote Control backup	See Item C-20
Degraded MCC backup (delay)	See Item M-5
Minor, Remote Control backup	See Item M-4
Minor, Remote Control backup	See Item M-3
Minor, Remote Control backup	Used after manned mission
Minor, Remote Control backup	See Item P-13
Minor, Manual & MCC backup	See Item P-3
Minor, Remote Control backup	See Items M-14 and M-11
Minor, Remote Control backup	See Items M-14 and M-12
Minor, Remote Control backup	See Items M-14 and M-11
Minor, Remote Control backup	See Items M-14 and M-12
Minor, Remote Control backup	See Items M-14 and P-9
Minor, Remote Control backup	
None, dual redundancy	Also, remote control backup
None, dual redundant	Also, remote control backup (M-2)
None, dual redundant	Also, remote control backup (M-2)
Minor, NAV data display backup	See Items N-8, N-9 and N-10
Minor, Remote control info backup	See Items N-8, N-9 and N-10

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B.5.2 Unmanned Mode (Remote) Mission Data

The following DLRV Remote Mode Mission Failure Modes and Effects Summary Sheets are included as tables in this subsection:

Table B.5-6	Mobility Subsystem (2 sheets)
Table B.5-7	Power Subsystem (2 sheets)
Table B.5-8	Communications Subsystem (2 sheets)
Table B.5-9	Navigation Subsystem (1 sheet)
Table B.5-10	Vehicle Borne Remote Control and Hazard Detection Subsystems (1 sheet)

TABLE

DLRV REMOTE MISSION FAILURE MODE AND EF

ITEM	COMPONENTS	ASSUMED FAILURE MODES
M1	AFT Unit Connections	Loss of power connector or wiring redundancy.
M7	Wheel Assemblies	Fatigue failure or damage of discrete element rings.
M8	Shock Dampers	Functional loss of 1 or more dampers.
M9	TDM Power Controller Channels	Loss of 1 or more of 6 TDM controller channels.
M10	SDM Power Controller Channels	Loss of 1 or more of 4 SDM controller channels.
M11	Traction Drive Mechanisms (TDM's)	Loss of drive motor (1 of 6). Loss of transmission (1 of 6). Loss of 2 or more TDM motors or transmissions.
M12	Steering Drive Mechanisms (SDM's)	Loss of 1 of 4 SDM motors or transmissions. Loss of 2 or more SDM motors or transmissions.

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B.5-6

ECTS SUMMARY SHEET MOBILITY SUBSYSTEM

FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATION
No effect on mission. Design intent is to provide complete power and critical functional wiring redundancy in separate cables.	None required.
Minor effect for single rings or pairs which do not overload adjacent rings. Extensive damage or ring failures will still allow vehicle to travel on inner rims.	Periodic inspection of wheels using TV or FAX cameras. Severely degraded wheel ring conditions will cause operator to avoid difficult obstacles or terrain.
Minor effect on damping function for affected wheels, damper limit stops and snubbers will restrain suspension arms.	Loss of dampers (sized for man mission speeds) will have little effect on 2 km/hr remote mission. Obstacle negotiation may require greater attention to prevent difficulty.
Minor or degraded mission effect depending on number of malfunctions and lunar traverse conditions.	TDMs may be mechanically and electrically decoupled by remote control to allow free wheeling.
Minor or degraded mission effect depending on number of malfunctions and lunar traverse conditions.	SDMs may be mechanically and electrically decoupled by remote control to allow wheels to free castor or be locked in fixed position if desired.
Minor. Mission may be continued with minor effect on speed and obstacle performance capability. Degraded mission or operating delays depending on number of malfunctioning and lunar traverse conditions.	TDMs may be mechanically and electrically decoupled by remote control to allow free wheeling. Same as above. More than one TDM failure may force operator to avoid the more severe slope and obstacle conditions.
Minor. Mission may be continued with negligible effect on mobility performance and control except in reverse driving. Minor effect or degraded performance depending on whether reverse driving mode is frequently needed.	SDM's may be mechanically and electrically decoupled by remote control to allow wheels to free castor or to lock in fixed position if desired. Same as above. More than one wheel dragging in reverse may cause unusual steering maneuver modes. Scuff steering may also be used as a backup if SDMs are fixed angle locked.

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TABLE B.5

DLRV REMOTE MISSION FAILURE MODE AND EF

ITEM	COMPONENTS	ASSUMED FAILURE MODES
M13	TDM/SDM Power Conditioners	Loss of 1 of 6 or more TDM/SDM chann Loss of 1 of 4 SDM channel functions.
M14	TDM & SDM power circuit breaker relays	Loss of 1 or more circuit breaker relay or power switch functions.
M16	TDM Mode Logic	Loss of power on/off speed control or braking inputs or output commands.
M17	SDM Mode Logic	Loss of steering angle or heading reference input or output command function.

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-6 (Cont.)

FECTS SUMMARY SHEET MOBILITY SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATION
ıels.	Minor or degraded mission effect depending on the number of malfunctions and lunar traverse conditions.	Both TDM and SDM for a given wheel must be electrically and mechanically decoupled by remote control.
r	Open CCBs will result in minor or degraded mission effect depending on number and traverse conditions.	CCBs or switches which cannot be reset by remote control will result in corresponding TDM or SDM decoupling procedures.
	No effect on mission. Standby redundant logic will provide backup functions.	Automatic switching of standby logic for single module failure.
	No effect on mission. Standby redundant logic will provide backup functions.	Automatic switching of standby logic for single module failure.

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TABLE

DLRV REMOTE MISSION FAILURE MODES AND E

ITEM	COMPONENTS	ASSUMED FAILURE MODES
P1	RTG (130 Watts)	Multiple internal open or short malfunctions. (Thermoelectric couples are series-parallel ladder networks).
P2	"Rechargeable" AG-ZN Batteries Units A & B	Loss of 1 of 2 batteries.
P3	RTG Short/On Relay	Loss of function.
P4	Switching Series Regulator	Loss of functions for 1 of 2 redundant units.
P5	Switching Shunt Regulator	Loss of function for 1 of 2 redundant units.
P6	Charge Regulators #1 & #2	Loss of functions - 1 of 2 redundant units.
P7	Charge Mode Relays #1 & #2	Open or short.
P8	Battery-Buss Select Relays #1 & #2	Open or short.
P9	Mobility Busses #1 & #2	Open or short.
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: B.5-7

FFECTS SUMMARY SHEET POWER SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Imminent mission abort. Loss of normal power source for astrionics, science, controls & DLRV heaters. Batteries may not be recharged.	Switching shunt regulator automatically supplies 28V buss for astrionics, DLRV will operate only until batteries are depleted.
	Mission degraded. Mission must be continued on 1 battery with more frequent stops for recharge of remaining battery and greater time if required to complete mission.	All battery loads may be switched by remote control to good battery for DLRV operation.
	Mission abort. Loss of ON function will degrade mission same as for RTG loss. See Item P1.	Switching shunt regulator will automatically provide 28V buss power required from batteries until batteries are depleted.
	No effect on mission. Standby redundant unit will automatically provide interbuss regulation.	None required. Second failure will degrade but not abort power subsystem.
	No effect on mission. Standby redundant unit will automatically provide RTG load regulator.	None required. Second failure will reduce system to operation on batteries plus RTG power provided through charge regulators.
	Minor effect on mission. Rate of battery recharge will be increased using one unit to charge each of 2 batteries alternately.	MCC may switch RTG power from one battery to another to balance energy return to both batteries.
	Minor effect on mission. Open failure mode will affect mission same as above. Shorted contacts will not affect normal functions.	Same as above (P6) except that shorted contacts will require no action.
	Open failure mode will put all mobility loads on 1 buss. Short failure mode will constrain buss switching.	MCC may switch both batteries and all mobility loads to 1 buss to complete mission in normal manner.
	Open failure mode will put all mobility loads on 1 buss. Short failure will have the same effect.	Same as above (P8).

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TABLE B.5

DLRV REMOTE MISSION FAILURE MODES AND E

ITEM	COMPONENTS	ASSUMED FAILURE MODES
P10	28 Volt Buss	Open or Short.
P11	DC-DC Converter Regulator	Loss of functions for 1 of 2 redundant units.
P12	RTG LC Filters	Open failure for 1 of 2 redundant units.
P17	Battery Amp-Hour Sensors	Loss of function.

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-7 (Cont.)

FFECTS SUMMARY SHEET POWER SUBSYSTEM

FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
Redundant wiring, spacing and insulation techniques plus diode or fuze protection to all loads prevent failure.	None. Redundancy and circuit protection provisions are automatic compensation.
No effect on mission. Parallel redundant unit will automatically provide unit decoder and telemetry power and regulation.	None required.
No effect on mission. Parallel redundant unit will automatically provide 28 volt buss power.	None required unless both units fail. Second failure will cause minor loss of RTG power being provided through charger battery and series regulator.
Minor affect on mission. Loss of sensors will not affect battery performance.	Remote control may compute depth of battery discharge using TM data for battery current and voltage vs time.

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TABLE

DLRV REMOTE MISSION FAILURE MO
COMMUNICATIO

ITEM	COMPONENTS	ASSUMED FAILURE MODES
C1	Directional Antenna and Microwave Network	Loss of Transmitting capability
C2	Directional Antenna Drive	Loss of azimuth and/or elevation driv functions.
C3	Omni Antenna and Diplexer	Loss of transmitting and/or receiving capability.
C4	Omni Diode Switch	Loss of Omni or S-band input, or receiver output functions.
C5	S-Band Receivers	Loss of 1 of 2 redundant receivers.
C6	Command Decoders	Loss of 1 of 2 redundant system deco
C7	Subsystem Decoders	Loss of mobility, power, science or astrionics decoder functions.
C8	Directional Ant. Diplexer	Loss of input/output functions.
C9	Directional Link Combiner	Loss of functions.

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; B.5-8

DES AND EFFECTS SUMMARY SHEET
NS SUBSYSTEM

	EFFECT ON MISSION	OPERATIONAL COMPENSATIONS
	Degraded mission. Reception of uplink not affected. TV tranšmission is severely restricted. Mission delay will be incurred by step mode only operations.	Omni antenna will handle all uplink data. TV frames require 6.5 minutes; 360° FAX requires 30 minutes per frame.
e	Degraded mission. Reception of uplink not affected. TV transmission is severely restricted.	Continue mission with FAX or with TV when the vehicle maneuvering can compensate azimuth loss or elevation loss (with backup solenoid for fixed elevation angle).
;	Possible aborted mission. All uplink and downlink data may be handled by directional S-band until directional antenna loses ground station. Communication will cease unless S band has search mode.	Directional S-band must be operated continuously. Addition of search mode would automatically restore lock to ground station.
	Minor effect on mission. Results in loss of ability to switch receiver and antenna combinations.	MCC may be required to alternate between communication service modes occasionally.
	No affect on mission. Standby redundant receiver will function for either omni or directional link modes.	Switching between redundant receivers is automatic if one fails.
lers.	No effect on mission. Standby redundant decoders will function for either omni or directional link modes.	Switching of redundant decoders is automatic.
	No effect on mission. Loss of specific decoders unlikely because of actual or functional redundancy.	Switching of redundancy functions is automatic.
	Degraded mission. Reception of uplink and transmission of downlink may be limited to Omni capabilities. (See Item C-1).	See mission compensation for Item C1, Directional Antenna and Microwave Network.
	Degraded mission. Transmission of downlink may be limited to Omni capability.	See mission compensation for Item C1, Directional Antenna and Microwave Network.

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TABLE B.5

DLRV REMOTE MISSION FAILURE MO
COMMUNICATIO

ITEM	COMPONENTS	ASSUMED FAILURE MODES
C10	FM Power Amplifier	Loss of functions for 1 of 2 redundant units.
C11	FM Exciter	Loss of functions for 1 of 2 redundant units.
C12	PM Power Amplifier	Loss of functions for 1 of 2 redundant units.
C13	PM Exciter	Loss of functions for 1 of 2 redundant units.
C14	Modulation Processor	Loss of functions for 1 of 2 redundant units.
C19	DLRV Borne Telemetry	Loss of isolated measurements.
		Loss of power supply or multiplex/ converter functions.

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-8 (Cont.)

DES AND EFFECTS SUMMARY SHEET
NS SUBSYSTEM

FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
No effect on mission., Standby redundant Amplifier will operate for either Omni or Directional links.	Switching between Amplifier units may be accomplished by remote control command.
No effect on mission. Standby redundant Exciter will operate for either Omni or Directional links.	Switching between Exciter units may be accomplished by remote control command.
No effect on mission. Standby redundant Amplifier will operate for either Omni or Directional links.	Switching between Amplifier units may be accomplished by remote control command.
No effect on mission. Standby redundant Exciter will operate for either Omni or Directional links.	Switching from primary to standby Exciter is automatic when PM Power Amplifier is switched.
No effect on mission. Standby redundant Processor will handle all TM data and science data.	Switching from primary to standby Processor is automatic when PM Power Amplifier is switched.
Minor effect on mission for loss of TM data since all critical measurements are functionally redundant.	Loss of isolated measurements are detected by MCC remote control and increased monitoring of functionally redundant data will support mission requirements.
Minor effect based on redundancy.	Same as above item C-19.

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TABL

DLRV REMOTE MISSION FAILURE MO
NAVIGATION

ITEM	COMPONENTS	ASSUMED FAILURE MODES
N-1	Vertical Gyro	Loss of accuracy or malfunction.
N-2	Directional Gyro	Loss of accuracy or malfunction.
N-3	Navigation Computer	None. Onboard computer noteused i remote control mode.
N-4	Odometer Selection & Counter Circuits	Loss of 1 or more circuits
N-5	Analog Multiplexer	Loss of redundant signal processing circuits.
N-6	A/D Converter	Loss of redundant functions.
N-7	Navigation Power Conditioning	Loss of 1 of 2 dual redundant sectio

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E B.5-9

)DES AND EFFECTS SUMMARY SHEET
SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
	Degraded mission. Mission time may be sacrificed for added navigation accuracy checks. Loss of vehicle attitude data required for TV camera syncronization.	Operator may use landmark recognition as an aid for navigation accuracy. Continuous mode driving with TV will be degraded and delay mission.
	Mission degraded. Navigation and steering significant mission delays will result due to loss of vehicle heading reference for steering mode logic and loss of vehicle heading data for earth based navigation.	If landmark navigation is not adequate for a given area, TV star fixes may be used for interim position fixes. DLRV maneuvers must be reduced commensurate with degraded steering using wheel angle position commands.
n	None, not applicable.	None, not applicable.
	Minor effect on mission.	MCC navigation would detect and disregard malfunctioning circuits.
	No effect on mission.	None, not applicable.
	No effect on mission.	None, not applicable.
ns.	No effect on mission. Standby redundant unit will automatically provide power and regulation to all NAV components.	None required unless both fail under short loading. Second failure may cause mission to be based on landmark recognition and earth plotting.
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TABLE

DLRV REMOTE MISSION FAILURE MC
VEHICLE-BORNE REMOTE CONTROL

ITEM	COMPONENTS	ASSUMED FAILURE MODES
RC1	TV Camera & Electronics	Loss of vidicon, camera power supp electromechanical optics controls o video electronics.
RC2	TV Camera Position Controls	Loss of azimuth (pan) or elevation (t controls.
RC3	Medium Range Hazard Sensor	Loss of sensor functions or related electronics.
RC4	Short Range Hazard Sensor	Loss of sensor functions or related electronics.

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B. 5-10

ꞁDES AND EFFECTS SUMMARY SHEET
ᴧND HAZARD DETECTION SUBSYSTEM

	FUNCTIONAL EFFECTS	OPERATIONAL COMPENSATIONS
ly, r	Degraded mission. Loss of continuous mode driving capability, and use of TV for navigation aid or science activity monitoring.	FAX camera may be used for step mode driving. Remote mission becomes more dependent on use of both medium and short ranges optical radar hazard detection.
ilt)	Degraded mission. Same effect as item RC1 except that loss of pan control will still allow degraded TV operation in step driving mode.	TV camera fixed on one azimuth may be used for step mode driving by maneuvering vehicle at each stop. FAX camera operation backup may be used.
	Minor effect on mission. Loss of medium range functional backup for TV in continuous mode. Short range radar still provides for vehicle safety.	TV operator must employ TV more for medium range observations in continuous and step modes. Short range radar may be activated more often if TV is less effective.
	Minor effect on mission. Both TV and medium range radar may be used as alternate mode functions.	Medium range hazard radar may be reoriented by remote control to operates as short range sensor.

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